INTERIM REPORT

ITS Impacts Assessment for Seattle MMDI Evaluation: Modeling Methodology and Results

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SECTION 1: INTRODUCTION

The purpose of this document is to present the methodology and preliminary findings of a modeling study conducted by Mitretek Systems in support of the evaluation of the Metropolitan Model Deployment Initiative (MMDI) program. This section describes the background of the study, the objectives of the experimental plan, the role of modeling with respect to national and local evaluation goals, and the schedule of major deliverables for the Mitretek modeling effort.

In February 1998, the ITS Joint Program Office (JPO) directed Mitretek to prepare a modeling study plan to support its ongoing evaluation effort for the Seattle MMDI deployment. The inclusion of Mitretek as direct support to the Seattle MMDI evaluation was made in light of time and resource constraints associated with the delivery of a national-level MMDI evaluation report in 1999. Mitretek, under the aegis of another JPO-sponsored effort predating the MMDI effort, had already developed a set of network models of Seattle suitable for the assessment of ITS impacts at a subarea and regional level. Leveraging existing Mitretek modeling assets allowed MMDI evaluation resources to be concentrated elsewhere, particularly given the time and effort associated with large-scale simulation network development and calibration.

The previous Mitretek modeling case study projected ITS impacts in the year 2020 from a range of potential transportation system improvements within a 120-square mile corridor north of the Seattle central business district. However, the 2020 forecast year models and data sets were not constructed with MMDI projects in mind, and Mitretek had to modify and re-calibrate them to reflect the near-term MMDI evaluation effort. A brief overview of the modeling framework, data sets, and scenario sets developed for that effort and their usefulness to the MMDI evaluation is presented in Section 1.1.

Given a set of resource constraints and the master schedule associated with the national MMDI evaluation program, Mitretek developed a plan in April 1998 [1] to tailor the existing the 2020 evaluation framework and data sets for the MMDI evaluation effort. The experimental design associated with that evaluation plan has been implemented with only minor changes to date (details in Appendix A). The experimental design attempts to deal with ITS impacts on two levels. First, through a set of simulation experiments referred to here as sensitivity analyses, hypotheses integral to the isolated deployment of projects in similar functional groupings (e.g., Advanced Traveler Information Systems (ATIS), Traffic Signal Control, Incident/Emergency Management, and Transit Applications) are explored. The sensitivity analysis is based solely on subarea simulation analysis. Second, interactions between projects deployed concurrently plus the impact on overall regional travel demand are examined through an integrated before-and-after alternatives analysis. The alternatives analysis features employs both subarea simulation and a regional planning model to assess impacts.

The Mitretek modeling analysis effort for MMDI has focused on project features that are difficult to evaluate with direct field measurement. For example, during the evaluation period, overall travel demand rose concurrently with overall utilization of web-based ATIS. Differentiating these impacts would be problematic at best using the existing data collection methods in the

Seattle area (primarily loop detectors). In cases like this, models can be helpful in systematically and independently quantifying the impacts of rising travel demand or web-based ATIS.

Likewise, the modeling effort also assists local MMDI partners in projective analyses of interest regarding specific projects. For example, MMDI-related improvements in arterial data collection and archiving facilitate the development of coordinated inter-jurisdictional traffic signal plans along major arterial corridors. However, participating jurisdictions are reluctant to implement these plans until impacts to both local and through traffic can be estimated. Here models are helpful in providing insight before a commitment to full implementation is made.

The focus of the modeling and simulation work is a reflection of the role it plays in supporting both national MMDI evaluation goals and the goals of the local partners. In support of the national evaluation, for example, the modeling work seeks to quantify relationships between rising ATIS market penetration and measures of overall system impacts such as throughput or energy consumption. Likewise, some experiments address more specific hypotheses of local interest. For example, in the traffic signal case discussed above, that integrated data collection, archiving and cross-jurisdictional cooperation have positive impacts on network efficiency both along and within the arterial corridor.

In order to meet these goals, the intent of the Mitretek modeling effort is not to explicitly evaluate the impact of each MMDI project, although where such impacts can be reliably estimated these impacts will be highlighted. Rather the focus is on testing hypotheses related to national or local goals, and to benchmark progress made in Seattle from the deployment of newly integrated ITS capabilities in the MMDI time-frame.

At this stage of evaluation, Mitretek modeling analysis provides direct evaluation support to 13 of 26 current Seattle MMDI projects. Up to 18 projects may be supported directly by the modeling analysis when the Mitretek effort concludes in the spring of 1999.

This document contains draft results for a final report to be delivered 1 April 1999. The goal of this interim report is to present initial findings, indicate the scope of the analysis performed to date, and to provide for meaningful feedback from evaluation participants before the 1 April final report date.

1.1 MMDI Evaluation and the 2020 Seattle North Corridor Case Study

Mitretek, at the request of the FHWA ITS JPO has been conducting a study unrelated to the MMDI effort entitled "Incorporating ITS into the Planning Process"[2]. As a part of that effort, Mitretek developed an ITS evaluation methodology for use within the constraints of the Major Investment Study (MIS) process applied in traditional transportation planning. This evaluation methodology has been dubbed the Process for Regional Understanding and EValuation of Integrated ITS Networks (PRUEVIIN). The PRUEVIIN framework has been applied in a case study of the Seattle metropolitan area for the 2020 time frame. Mitretek's general approach in support of the Seattle MMDI evaluation has been to adapt the models and data sets associated with the Seattle 2020 effort, efficiently and in a timely manner, to address the specific concerns of the Seattle MMDI evaluation effort.

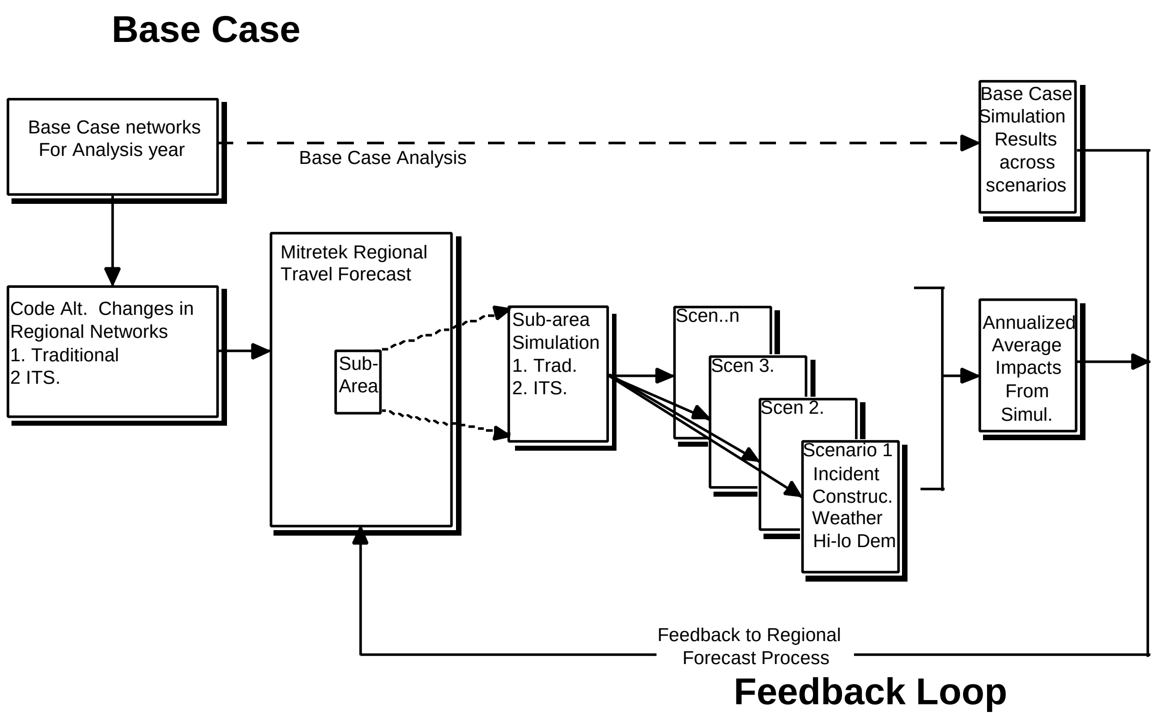

Figure 1.1 Evaluation Framework

Mitretek's PRUEVIIN framework features a traditional four-step transportation planning model as well as a traffic simulation to capture regional and corridor-level ITS impacts (Figure 1.1). MIS-style analyses typically deal with meeting transportation needs for a particular corridor. In the Seattle 2020 effort, the corridor under study (dubbed the Seattle North Corridor) is a roughly 120 square-mile corridor running north from downtown Seattle to Everett, WA bounded by Puget Sound on the west and Lake Washington on the east. The North Corridor data set models 350,000 vehicles traversing a network containing over 2,200 links. Transportation facilities in the corridor were identified and coded in the two models based on projections of infrastructure and travel demand associated with the 2020 forecast year for the morning peak period (6:00 AM – 9:30 AM).

Each alternative's performance is evaluated using a combination of regional planning model and the subarea simulation model. The regional planning model is employed to identify impacts on travel demand including trip distribution, mode choice and regional assignment. The regional travel demand model represents long-term adaptation by the travelers in the system to average conditions experienced in the peak period.

Traffic simulation is employed within the boundaries associated with the North Corridor subarea. The role of the simulation is to capture effects associated with the day-to-day and within-day variation in conditions associated with peak period travel. To this end, the simulation is exercised through a series of 30 representative scenarios. Each scenario describes a particular combination of weather impacts, travel demand variation, as well as a pattern of incidents and accidents in the system. The scenarios were derived from a cluster analysis of the traffic flow data (for variations in day-to-day travel demand) and weather/incident impacts (taken from historical archives). Each scenario has a weight or probability of occurrence and the scenarios taken together comprise a representative year of operation.

Simulation analysis over the representative year of operation allows for a meaningful linkage between the two modeling scales. Impacts by scenario can be rolled into an annual average and compared with baseline travel in the regional model. These in turn produce a change in overall regional demand that can be re-analyzed with the simulation.

The fact that North Corridor network data sets had been developed, tested and calibrated as a part of the previous study proved of great benefit to the Seattle MMDI evaluation since the time-consuming task of generating a network was avoided. Since schedule and budget constraints precluded new network generation, simulation analysis in support of the MMDI evaluation was necessarily confined to the North Corridor subarea. The majority of Seattle MMDI projects are deployed within the North Corridor, although some projects are not present in the corridor whatsoever. The eight projects not present in the corridor are not modeled in this study.

Results from this study should be understood in context of the North Corridor impacts. The mix of ITS technologies, congestion levels, weather and other factors seen in the North Corridor are representative of the Seattle region. While representative, the North Corridor impacts should not be viewed as the sum total of MMDI-related impacts. Similarly, extrapolation of subarea impacts in the estimation of overall regional impacts should be conducted with close consideration of the particular attributes of the North Corridor.

1.2 Relationship of Mitretek Modeling and Seattle MMDI Projects

Project	Project Title	Dropped By MMDI	Mitretek Project Groupings ATMS	ATIS	IMS/EMS	Transit	Integ.	Not Modeled
SE-1	North Seattle ATMS		M					
SE-2	Eastside ATMS							M
SE-3	Southside ATMS							M
SE-4	Seattle ATMS							M
SE-5	SeaTac Airport TMS							M
SE-6	Bellevue TMS							M
SE-7	Northwest TSMC		M					
SE-8	Olympic TSMC							M
SE-9	Regional Video				M			
SE-10	Bartizan	M						
SE-11	XYPoint	M						
SE-12	Incident Capture				M			
SE-13	Incident Video				M			
SE-14	Emergency Ops Center				M			
SE-15	King County AVL					M 1		
SE-16	AVI Bus Signal Priority					M 1		
SE-17	Microsoft Sidewalk			M				
SE-18	Etak/Metro/Seiko			M				
SE-19	Fastline HPC			M				
SE-20	Cable TV			M				
SE-21	WIN Kiosks	M						
SE-22	Seattle Center Parking							M
SE-23	Riderlink/Busview					M 1		
SE-24	King Co. Transit Display					M 1		
SE-25	WS Ferries ATIS							M
SE-26	WSDOT Web Page			M				
SE-27	Traffic Telephone			M				
SE-28	Dynamic Rideshare					M 1		
SE-29	ITS Backbone						M	
	Total	3	2	6	4	5	1	8

Note: 1 = Optional, unlikely to address until after 4/1/99

Table 1.1 Mitretek Modeling and Seattle MMDI Projects

Table 1.1 updates progress to date from the April 1998 plan in terms of Mitretek modeling activity with respect to each of the 29 projects contained in the Seattle MMDI proposal. Three projects (XYPoint, Bartizan, and WIN Kiosks) have been dropped from the Seattle MMDI. Of the remaining 26, 13 are supported by this modeling effort directly and have results in this document. These 13 projects fall under the ATMS, ATIS, IMS/EMS, and Integration project groupings. A fifth project grouping, Transit, has five components that could be supported through Mitretek modeling, but have not been modeled to date. Results from the North Seattle ATMS project (SE-1) have indirect bearing on four other arterial traffic management projects (SE-2,3,4,6) since they are functionally equivalent but deployed in different geographic areas.

Mitretek modeling does not address another four projects beyond the SE-2,3,4,6 ATMS grouping. In each case this is because the projects are wholly outside of the North Corridor study subarea and have no functional analogs within the subarea.

The project groupings are used to identify projects that utilize the same kinds of technologies or integrate similar traffic control components. Hypothesis and impacts associated with projects within a grouping are performed using similar techniques, detailed in Section 3. In some cases, projects are grouped because the impact of a single project acting in isolation has either no impact or an impact that cannot be measured in the simulation. For example, the Incident Video project (SE-13) alone has no impact unless it is coordinated through the Northwest TSMC (SE-7) and linked to more effective incident management. In this case it is only natural to consider these projects together when they support a particular ITS component or user service.

The ATIS project grouping is further differentiated into two subgroups: pre-trip and en route ATIS services. The PRUEVIIN framework cannot discriminate effectively between two media being employed to deliver similar messages at the same decision point in a trip. For example, the data viewed pre-trip on Cable TV (SE-20) or Microsoft Sidewalk (SE-17) is based on the same real-time source as the WSDOT web-site (SE-26). However, the simulation model can differentiate between the same data being presented pre-trip versus en route, for example, highlighting differences between Fastline PC (SE-19) and the Cable TV (SE-20).

In summary, the ATMS grouping includes projects that serve to archive and consolidate arterial traffic data from a number of sources in a central location. The ATIS project grouping comprises a collection of pre-trip and en route information services presenting current congestion conditions based on real-time WSDOT freeway detector data. The IMS/EMS grouping is composed of projects that (among other goals) seek to improve detection, response time, and freeway system efficiency under incident conditions. The Transit grouping is a collection of transit-related improvements intended to provide real-time information to bus riders or to improve the management capabilities of transit operators. The Integration grouping contains only one project, ITS Backbone (SE-29), that allows for data collected from arterial sensors for the purpose of traffic signal control to be utilized in support of ATIS.

1.3 Alternatives Analyses and Sensitivity Analyses

The PRUEVIIN framework is designed to support alternatives analysis. That is, a set of well-defined alternatives is proposed as potential solutions to meeting projected corridor travel demand. These alternatives may contain specific ITS components as well as traditional infrastructure construction components. Corridor level impacts of each alternative are predicted by the use of the meso-scale traffic simulation. Regional travel demand impacts are predicted by the traditional four-step regional planning model. A limited feedback mechanism is used between the two models to reflect changes in average or perceived corridor conditions that may impact regional travel considerations.

For the Seattle 2020 analysis, a strict alternatives analysis was sufficient to meet all the goals of a 20-year forecasting effort. However, a direct application of an alternatives analysis was less appropriate for the needs of MMDI evaluation. First, the set of enhancements to the current ITS infrastructure in Seattle that the MMDI projects represented did not easily fit the well-defined in-or-out precepts of direct alternatives analysis. In many cases, the MMDI projects represented the connecting together of isolated capabilities or the incremental extension of existing technologies. In some cases, the impact of these data-sharing capabilities were not implemented as a part of MMDI, but established a necessary condition for any future implementation. For this reason, the before and after alternatives considered for the MMDI evaluation are "Baseline" and "Enhanced ITS." The Enhanced ITS alternative (defined in detail in Section 3.4) represents a combination of improved ITS capabilities deployed in the MMDI deployment time-frame, an increase in users of web-based ATIS, and a set of projective improvements to signal coordination facilitated but not implemented during the MMDI time frame.

Finally, a direct application of the alternatives analysis does not meet the MMDI evaluation goal of providing impact measures on specific hypotheses. The alternatives analysis of the Baseline and Enhanced ITS cases provides estimates of overall corridor-level and regional level impacts from concurrent deployment of MMDI-related improvements. In order to meet the local and national-level MMDI evaluation requirement for testing a number of specific hypotheses, a range of sensitivity analyses have also been conducted. These sensitivity analyses consider the corridor simulation alone without runs or interaction with the regional model. Since feedback to the regional model significantly increases the computational load associated with each experiment, and cannot be performed within the national MMDI master schedule, feedback is only performed for the alternatives analysis. That said, the two-pronged strategy (alternatives plus sensitivity analysis) helps to meet the need for both individual project analyses and a desire to evaluate the "big-picture" impact of integrated MMDI deployment on regional travel. The regional impact is particularly important for meaningful analysis of energy and emissions impacts.

1.4 Deliverables of the Mitretek Seattle MMDI Evaluation Effort

This document represents the draft report deliverable to the JPO by 1 January 1999. Mitretek has agreed to provide a final report by 1 April 1999. The final report will also contain extensions or alterations to the results reported here based on additional analytical work to be conducted between 1 January 1999 and 1 April 1999. Contents of these reports are coordinated with the contractors handling the construction of the national-level MMDI evaluation reports, and may appear wholly or in part in those documents.

SECTION 2: APPROACH, METHODOLOGY AND MODEL CALIBRATION

This section presents detail on changes to the PRUEVIIN framework for MMDI evaluation; the set of 30 representative scenarios used to estimate annual impacts; the role of field data and survey results, traveler expectation modeling; and the results of calibration in both the regional planning model and the subarea simulation.

2.1 Modifications to the PRUEVIIN Framework

For MMDI evaluation, the PRUEVIIN methodology has been modified slightly from the technique used in the Seattle 2020 alternatives analysis. First, in that analysis, impacts in eight of 30 representative day scenarios were estimated using simple interpolation techniques. For MMDI, all 30 scenarios are run in the simulation and no interpolation is used. Second, for this preliminary report, no real-time mode choice is modeled. Recent survey data (see below) indicates that only 1% of current commuters consider mode choice when viewing real-time congestion reports. Mitretek testing indicates that, at this level of utilization, the impacts of such choices are too small to be measured against background randomness in the simulation model.

2.2 Measures of Effectiveness

For each experiment, measures of effectiveness (MOEs) for several of the JPO-designated Few Good Measures (FGM) will be calculated. In the corridor subarea, simulation outputs are analyzed to compute average system delay and total vehicle throughput. Throughput defined as the number of trips selected from the total traveler population that can complete trips within the AM peak period modeled. Other measures calculated include the coefficient of variation associated with day-to-day travel variability, the number of severely delayed trips (more than 15 minutes of delay or 150% of expected travel time). Similar statistics may be reported for each of the various traveler classes (for example, Fastline PC users or travelers guided by pre-trip information from the WSDOT Website). For the region, Mitretek will report the following MOEs: total VMT and VHT, mode share, accessiblity (a measure of transit service breadth) and average travel time.

For energy and emissions estimates, Mitretek plans to post-process simulation data on subarea energy and emissions impacts. In order to maintain consistency with ongoing emissions impacts assessments in Phoenix and San Antonio, Mitretek will implement post-processors developed by the ITS Program Assessment (IPAS) contractors performing those analyses. The IPAS contractors are responsible for the development and delivery of these simulation data post-processors to Mitretek.

To date, the energy and emissions post-processors are still in development. Therefore, this document contains no energy and emissions results. These post-processors must be available on or before 1 February 1999 in order for Mitretek to address environmental impacts in the final results document to be delivered 1 April 1999.

2.3 Scenario Set

The set of evaluation scenarios developed for the Seattle North Corridor are composites of several kinds of data collected during the study and are based on conditions seen in the morning peak period (6:00 AM - 9:30 AM). Three sources of system variability were investigated: the impact of incidents and accidents on localized network capacity, the impact of weather (including fog and visibility effects) on global network capacity, and variation in day-to-day travel demand.

Data on accidents was collected and analyzed from a number of sources. In the Seattle region, the impact of accidents are tracked and recorded in two databases depending on accident severity. Incidents are the most severe form, involving an hour or more of Washington State DOT activity to clear. Accidents are all events (including shoulder and partial lane blockages) recorded by the State Patrol. Various types of records were examined in the period 1991-1998. From these records, a cluster analysis of incident temporal and geographic position was performed. These in turn lead to the development of probabilistic distribution of accidents of varying severity for use in the evaluation scenarios. In the simulation analysis, accidents (including incidents) are modeled as temporal reductions in link capacity.

Similarly, a weather analysis was performed based on hourly weather observations over the period 1994-1995. Three conditions are incorporated into the evaluation scenarios: clear, rain and snow/frozen. Rain also includes limited visibility impacts of fog. In the simulation analysis, these impacts are modeled as global reductions in network maximum travel speed, capacity and speed at capacity. The reduction values selected in each case are consistent with HCM estimates and several publications on weather impacts. [3,4,5]

Finally, the variation in corridor travel demand was estimated from observed flow rates at a set of freeway and arterial detector stations throughout the area. These peak-period flow rates were analyzed over all weekdays in the years 1994-1995 to identify patterns of variation. These variation factors are included in the simulation model through uniform scaling up or down of origin-destination flow rates.

The scenario set represents a cross-section of the conditions seen in the AM peak period using the three data sets (incidents, weather and demand variation) and is illustrated in Figures 2 and 3. These figures show the 30 scenarios organized in two dimensions by changes in roadway supply and travel demand. The relative size of the boxes for each scenario reflects the probability of occurrence, that is, the larger the box the more likely that particular scenario is to occur.

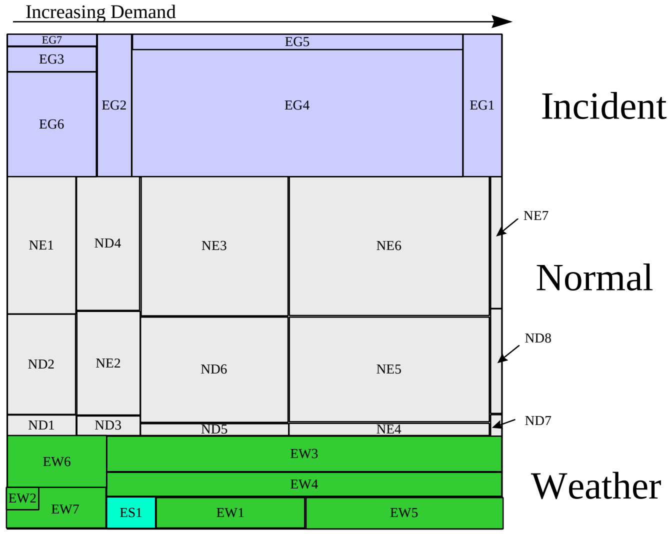

Figure 2.1 Evaluation Scenarios Shaded by Roadway Supply Impacts

In Figure 2.1, the scenario mapping is shaded by impacts in roadway supply into three subgroups: Incident (scenarios with good weather and more than 9 accidents), Normal (good weather and fewer than 9 accidents), and Weather (rain or snow). The relative intensity of the disruption increases as one moves from scenarios in the center of the mapping to the top or bottom edges of the mapping.

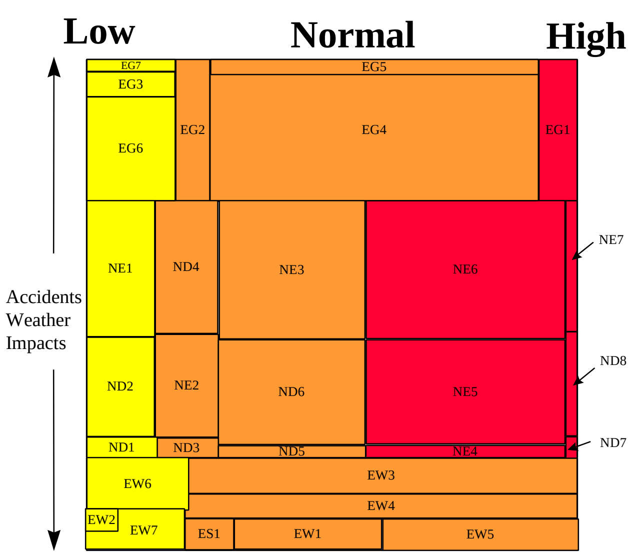

Figure 2.2. Evaluation Scenarios Shaded by Roadway Supply Impacts

Figure 2.2 presents the same mapping but has been shaded to reflect changes in travel demand with respect to the average conditions observed. Again, three subgroups are presented: Low (a 10% reduction or lower in expected demand), Normal (demand within plus/minus 10% of average), and High (a 10% or higher than expected demand pattern). The relative deviation from expected demand increases as one moves from scenarios in the center of the mapping to the left or right edge of the mapping.

Mappings of this type allow for two important analyses to be performed on model outputs. First, quantified impact measures (say travel time) in each scenario can be multiplied by the likelihood of the scenario and an average annual impact computed. These point estimates of average conditions are critical for both interaction with the regional model, as well as in modeling the impact of advanced traveler information systems or determining the effectiveness of signal timing plans. Second, the mappings themselves can be color-coded by ITS impact to illustrate the conditions under which ITS components provide the most significant impacts.

2.4 Field Data Sources and Survey Findings

A range of data sources has been utilized for the purposes of this study: data detailing project deployments; data on market penetration and customer response; and data on observed travel times and flows in the system.

First, detailed data on the MMDI projects themselves have been collected from WSDOT and other local sources. These data points identify the detector locations, jurisdictional boundaries for traffic signal control, VMS location and control, and other factors. How these data points are included in the analysis is detailed in Section 3.

Second, the primary source of data on market penetration and traveler response to information provision is the 1997 PSRC panel survey data. Jane Lappin (Volpe) and other researchers from the MMDI evaluation effort provided a useful summary of the survey results with respect to ITS issues. Again, the details of how this data is utilized in the modeling effort appear in Section 3. Additional data from ongoing customer satisfaction survey work for MMDI is expected in early 1999. In May 1998, Mitretek produced a document listing a range of data points and questions potentially to be answered through the customer satisfaction data surveys. When this data becomes available, Mitretek plans a complete review of ATIS-related simulation parameters as well as ATIS modeling approach in light of any new findings.

Third, travel time and flow data have been analyzed to provide a calibration data set for the subarea simulation model. The details of that data set and the calibration process are described in Section 2.7.

2.5 Traveler Expectation Modeling in PRUEVIIN

We characterize the provision of real-time information to travelers as attempts to bridge an "information gap" between the conditions that travelers expect to see when they make travel decisions and the actual current conditions of the system. Without any outside information, travelers only know the state of the network that they can visually inspect and make decisions based on experiential knowledge of typical network conditions. In our study, we use travel-time as a surrogate for overall traveler utility (within the same mode of travel). What this means is that travelers are assumed to seek generally faster time paths in the network when such paths can be identified based on known conditions and experiential knowledge base.

When travel-time information is provided to the traveler, the impact of that information must be considered in light of its source, the precision of the estimate, and the breadth of the network covered by the message. Finally, how that information is utilized depends on how knowledgeable the traveler is about congestion in the system.

Currently, travel time information is collected along the I-5 freeway within the corridor and centrally archived. This archive is utilized by public-sector agencies through Highway Advisory Radio (HAR), variable message signs (VMS), and an internet-based pre-trip planning service to provide travel time information or simple warnings to travelers in the system. For example, in response to a "Congestion Ahead" VMS message, an experienced traveler is more likely to divert from the freeway than a traveler unfamiliar with the network. Further, this experienced traveler is likely to choose a more efficient diversion route based on a presumably richer and more comprehensive knowledge of network conditions. If new detectors broaden the coverage of information or new services provide more precise estimates of delay, then travelers will have more detailed or more comprehensive information on which to base travel decisions.

In order to capture these differences, an expectation-setting process is required to meet two key analytical goals. First, a series of habitual routes have to be established which describe the paths typically taken by travelers in the system. Second, the travel times associated with these expected network conditions must be determined. Note that for our notion of expectation to hold, these two representations must be consistent -- that is, if vehicles traverse these habitual routes they will experience the expected travel times. Conversely, if vehicles traverse the network according to fastest paths associated with the expected travel times they will follow their habitual routes.

The expectation-setting technique employed in the Seattle network is an extension of the SAVaNT simulation feedback method developed by at the University of Michigan [6,7,8]. The expectation-setting framework is illustrated in Figure 2.3. Simulation input data corresponding to a clear weather, no incident and average travel demand day is input to the traffic simulation. All vehicles are set as if they are probe vehicles and report travel times to a central facility. A mix of familiar and unfamiliar drivers is generated for the simulation. In this first run, dynamic fastest-path routes for familiar drivers (i.e., commuters) are identified using an internal multi-path feedback strategy. This strategy computes a new set of fastest paths for 20% of commuter traffic every 400 seconds. A second group is provided fastest paths 400 seconds later, and so on until five groups of vehicles have been routed. After all subgroups have been updated once, the process begins again with the first subgroup. The result is that every vehicle is re-routed at 2000 second intervals based on complete network travel time information. Recall that this simulation run represents the average or expected network conditions. Thus, the internal route adjustment process reflects a familiar driver's adjustment in network congestion experienced on a recurring basis at different points and times.

This first run produces a set of habitual commuter routes. These routes provide paths for each subgroup from any node in the network to its ultimate destination based on 2000-second intervals. For the Seattle network, this is a 70+ MB file. At this point, however, the routing table is based on network conditions associated with only the first run and not on equilibrated expectation. To achieve this goal, 10% of the vehicles are instructed to follow not the habituated paths but the fastest paths associated with a historical link travel time profile updated every 15 minutes. An iterative process is seeded with the results from the initial run. As the process iterates, the historical link travel time profile is updated. This iterative process continues until the performance of the vehicles routed based on historical information is statistically equivalent to that of the vehicles based on fixed routes.

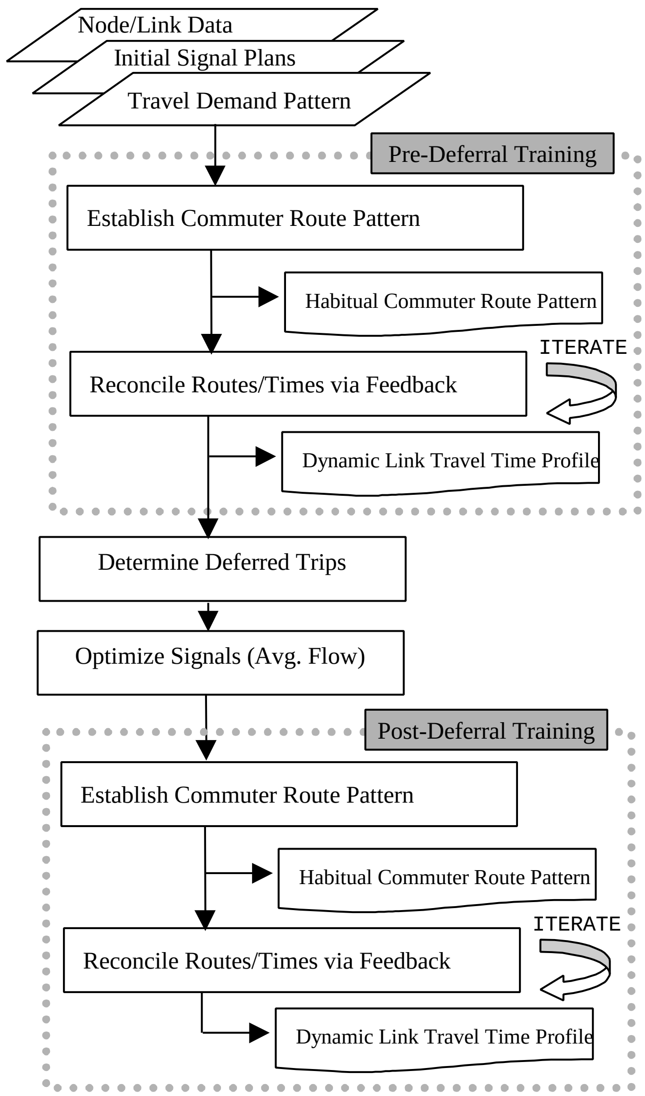

Figure 2.3 Expectation-Setting Process

Next, a subset of trips is identified for potential deferral to an off-peak time. This step was developed for the Seattle 2020 network when it became clear that travel between particular origins and destinations became highly congested at certain times in the peak period. When the average travel speed between points in the network dropped below the 10-km/hr threshold, a fraction of the total trips between these points was removed from the trip table depending on the magnitude of the delay. The deferral process, in combination with the regional travel demand model, produces higher expected travel demand for alternatives with the highest non-incident capacity. In the 2020 case study, the amount of travel deferred was typically small (2-5% of travel depending on the alternative). Less than 1% of travel demand is deferred at 1998 congestion levels.

After deferral, travel demand is lower and overall network congestion is lower. Therefore, the habituated route patterns of the commuter population determined in the Pre-Feedback Training process (based on the higher, pre-deferral demand) are no longer accurate. In order to compensate for this change, experienced commuters are re-trained a second time using the same iterative feedback technique utilized before the deferral process. The result is the generation of a routing file and a travel time file that are consistent with one another and conforms to expectation.

Unlike commuters, the unfamiliar driver's knowledge base does not contain any information on average temporal and geographic distribution of congestion. Routes are determined for these drivers based on estimates of uncongested travel times. The process represented here is map-scanning by travelers who imprecisely reckon their best route based on facility class and distance. The data model representing the knowledge base of the unfamiliar driver has the same structure as the commuter model, but contains less detailed, less accurate estimates of link travel times. Rather than a set of 15-minute estimates of link travel time, a single static estimate is calculated using free-flow (uncongested) travel time plus a uniform error. Routes are selected from this data model using a fastest-path calculation.

2.6 Network Calibration Initial Data Sets

As outlined in the April 1998 evaluation planning document [1], Mitretek considered several options for the development of a representative present-day network and travel demand pattern from the data sets used in the 2020 Seattle case study. Mitretek had in hand a 1990 network data set both at the regional and subarea level for the purposes of validation and calibration of simulation parameters in the data set. That calibration data set contained the following elements:

- modified regional (EMME/2) network
- regional 1990 demand files (circa 1995)
- modified and validated regional process (circa 1995)
- INTEGRATION 1.5x 1990 corridor network
- INTEGRATION 1.5x 1990 corridor demand files

The data set was calibrated against link flow data collected over the calendar years 1994-1995 and time-variant travel time estimates for freeway trips during an eight-month period in 1997. The target in this case was to replicate within-day travel time variation for the AM peak period under average demand, clear weather, and no accident conditions.

In order to develop a present day (1997/1998) network representation for the Baseline alternative, Mitretek examined three options. The first option is to use the 1990 networks (regional and corridor) as is, with overall travel demand factors adjusted upward based upon regionally accepted zonal growth rates to match 1998 travel demand estimates. Other options included systematic examination of differences between current Puget Sound Regional Council data sets or a complete re-calibration of both regional and subarea models.

Given the time constraints and the amount of analysis planned, Mitretek chose the first option. Section 2.7 describes the process by which Mitretek developed the 1997/1998 Baseline regional networks and travel demand using option one. Section 2.8 describes the resulting impacts on the subarea simulation travel demand as well as the results of comparing observed archived travel time data and simulated travel time data on an annual basis.

2.7 1998 Regional Planning Network Development

Section 1 provided a brief overview of the Process for Regional Understanding and Evaluation of Integrated ITS Networks (PRUEVIIN) for evaluating improvements in a transportation corridor (see Figure 1.1, a detailed description of the PRUEVIIN process and its application in a 2020 Seattle Case Study is provided in Mitretek 1998 [2]). In PRUEVIIN each alternative's performance is evaluated using a combination of two forecasting processes: (1) A regional "planning" level four-step travel forecasting process; and (2) A sub-area simulation and representative day analysis. The regional planning analysis represents the recurrent/average conditions "perceived" by travelers and the impacts that changes in these conditions have on regional travel patterns and demand within the analysis period (i.e. AM peak period). This information is then fed into the sub-area simulation and representative day analysis to capture the effects of within day and day-to-day variation, system operational response to conditions, and the value of information to travelers. In order to evaluate the impacts of improvements in a corridor the analysis is carried out for a base case (without the improvements) and one or more alternatives (with improvements).

This section provides an overview of the development of the 1997/1998 Baseline networks and travel demand for the Seattle MMDI Evaluation. Several options for this development were described in the previous section. As stated, the first option was chosen given the time schedule and data availability. This consisted of:

- Installing and verifying the available regional four-step travel forecasting process. The process used is an extension of the Puget Sound Regional Council (PSRC) process developed for Mitretek's previous work on Incorporating ITS into Corridor Planning: Seattle Case Study [2]
- Establishing the Baseline networks and transportation system representation. The previously developed 1990 networks system characteristics were used [2]
- Updating the socioeconomic (e.g. zonal population, employment, income) and other exogenous inputs to 1997/1998 conditions

- Executing the 1997/1998 travel forecasts and providing the resultant travel demand to the sub-area simulation process

Each of these is briefly discussed below. A request for updated 1997/1998 information (networks, demographic data, models) was made to the Seattle MMDI Evaluation liaison with a heads up to PSRC in early August. The formal request was made to PSRC on September 18th. PSRC was in the middle of a model and forecast update and could not respond with official numbers until later in the year. It was therefore decided to derive "best guess" estimates of 1997/1998 inputs using data that could be obtained from available sources (see below). The results described in this report are based upon these "best guess" inputs. PSRC did respond to the data request on November 24th providing updated 1995 and 2000 networks, demographic and trip generation files, and regional model (EMME/2) macros and parameters. If desired, this new information could be used for additional evaluation efforts carried out during 1999.

Regional Travel Forecasting Process: The regional travel forecasting process represents average recurring characteristics and conditions in a transportation network/system. It then captures and forecasts travelers responses to these "expected" conditions. An extension of the Puget Sound Regional Council's (PSRC) Regional Travel Modeling Process (EMME/2 travel forecasting package macros and programs; base transportation networks; and demographic files as obtained from PSRC in October 1996) developed for the Seattle Case Study [2] was adopted as the initial starting point for the regional travel forecasting system used in this study. The PSRC forecasting process is a "traditional four step" travel forecasting process (i.e. 0. Land use/socio-economic forecasting and data preparation, 1.Trip Generation, 2. Trip Distribution, 3. Mode Split, and 4. Assignment) and described in detail elsewhere [22,23]. Only slight modifications were made to the PSRC (circa, 1996) process for the Seattle Case Study to account for additional network detail required by the subarea simulation and to provide consistent "seed" network characteristics across all alternatives. The model development is described in detail in the Seattle Case Study documentation [2]. Also, for the current study a "growth factoring" process was used to expand the 1997/1998 productions and attractions from 1990 instead of the PSRC's more complex iterative Land use /demographic/ trip generation procedure used for forecasting into the future.

The resultant regional travel forecasting process used for this study is shown in *Figure 2.4: Regional Travel Forecasting Process for Seattle MMDI Evaluation.* As shown in the figure to produce an alternative's regional forecast, the alternative is coded and trip generation is performed. Then the trip distribution, mode split, and assignment steps are carried out. The assignment results are then fed back to mode split and trip distribution. Typically, 3.5 full feedback iterations are performed (iteration 0 assigns a seed trip table to obtain initial congested times for trip distribution and mode split). As stated, one slight modification to the PSRC model setups has been made for consistency across the alternatives. The study process starts with the same "seed trip tables" for each alternative. For the Seattle MMDI Evaluation these were the 1990 validated trip tables from the previous Mitretek Seattle case study [2].

The development of the 1997/1998 inputs to the regional forecasting process: the networks, socioeconomic, and other data are described next.

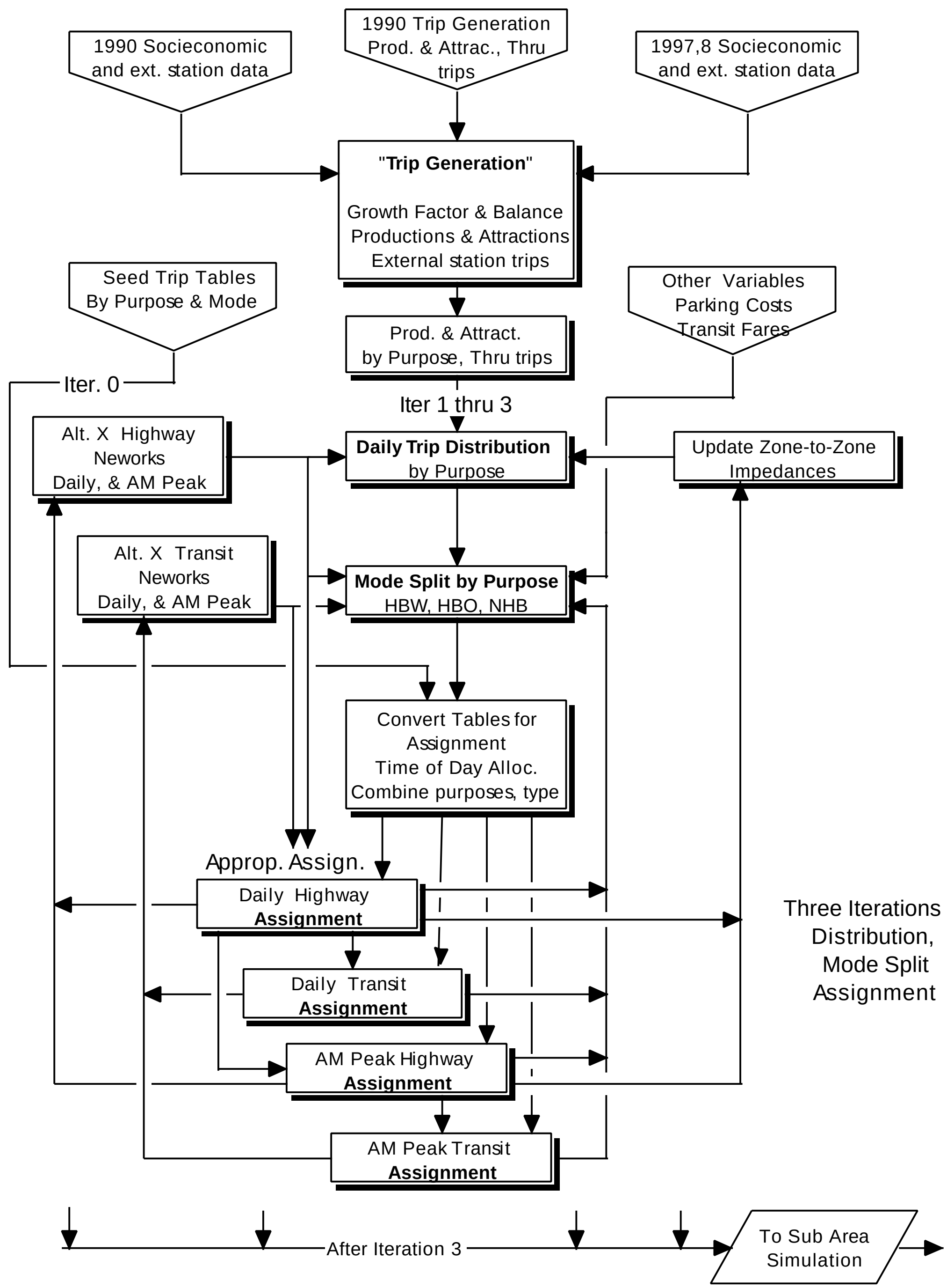

Figure 2.4, Regional Travel Forecasting Process for Seattle MDI Evaluation

Transportation Network and System Representation: In regional and subarea simulation forecasting processes travel demand is represented by calculating trips between traffic analysis zones. Trips (both vehicle and person) are assigned a route over the transportation network based upon the characteristics of each segment (length, capacity, time, delay function). Figures 2.5 and 2.6 show the regional and subarea simulation zone systems and networks used for the Seattle MMDI Evaluation. At the initiation of the modeling effort current year (1197/998) networks were not available for the region. A cursory review of transportation improvements within the simulation corridor was consequently made. Based upon this review it was decided that the 1990 networks developed and validated as part of the previous Mitretek Seattle case study for incorporating ITS into corridor analyses would provide a good representation of the corridor baseline conditions for the MMDI evaluation.

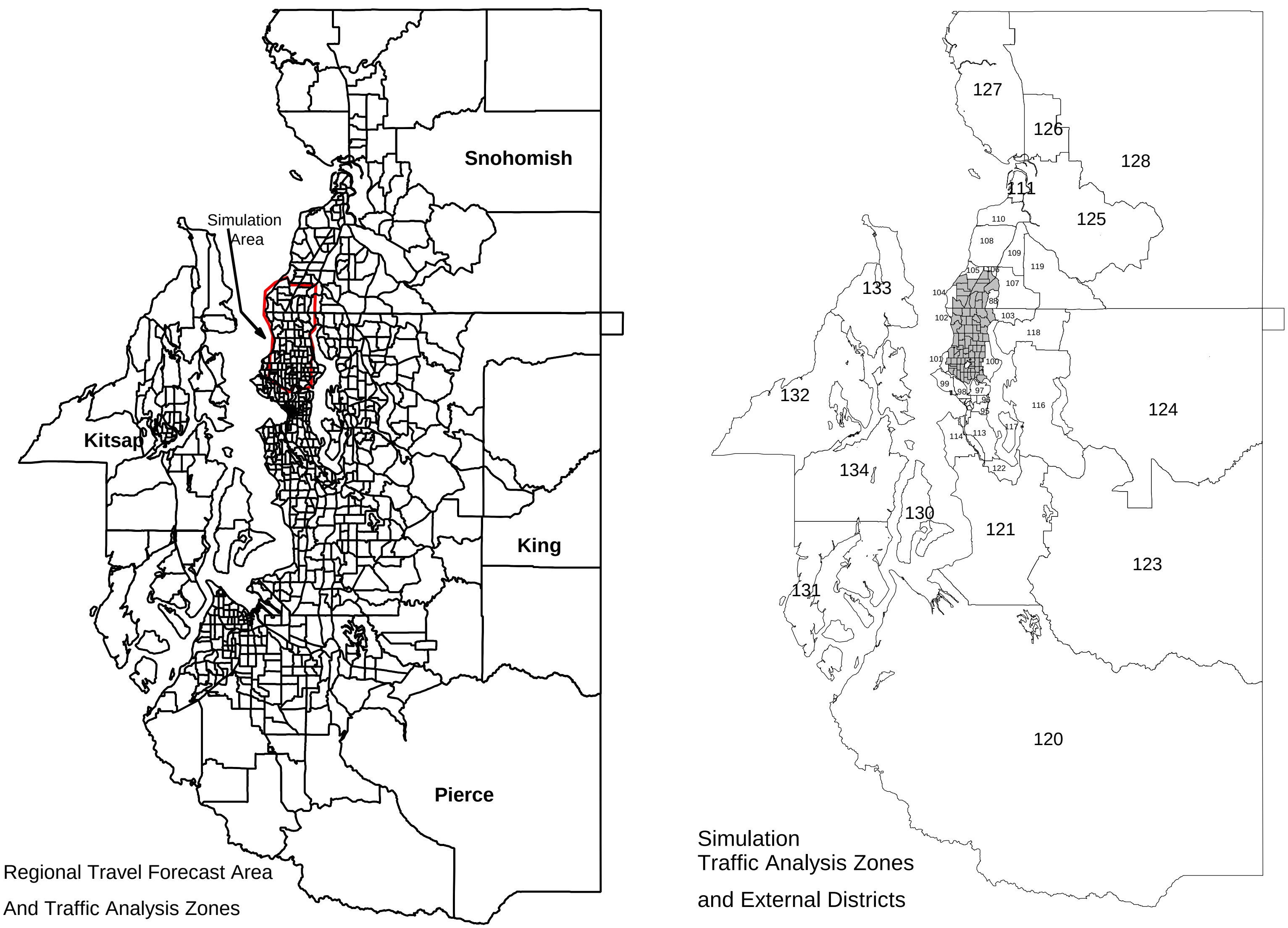

Figure 2.5 Regional and Subarea Zone Systems

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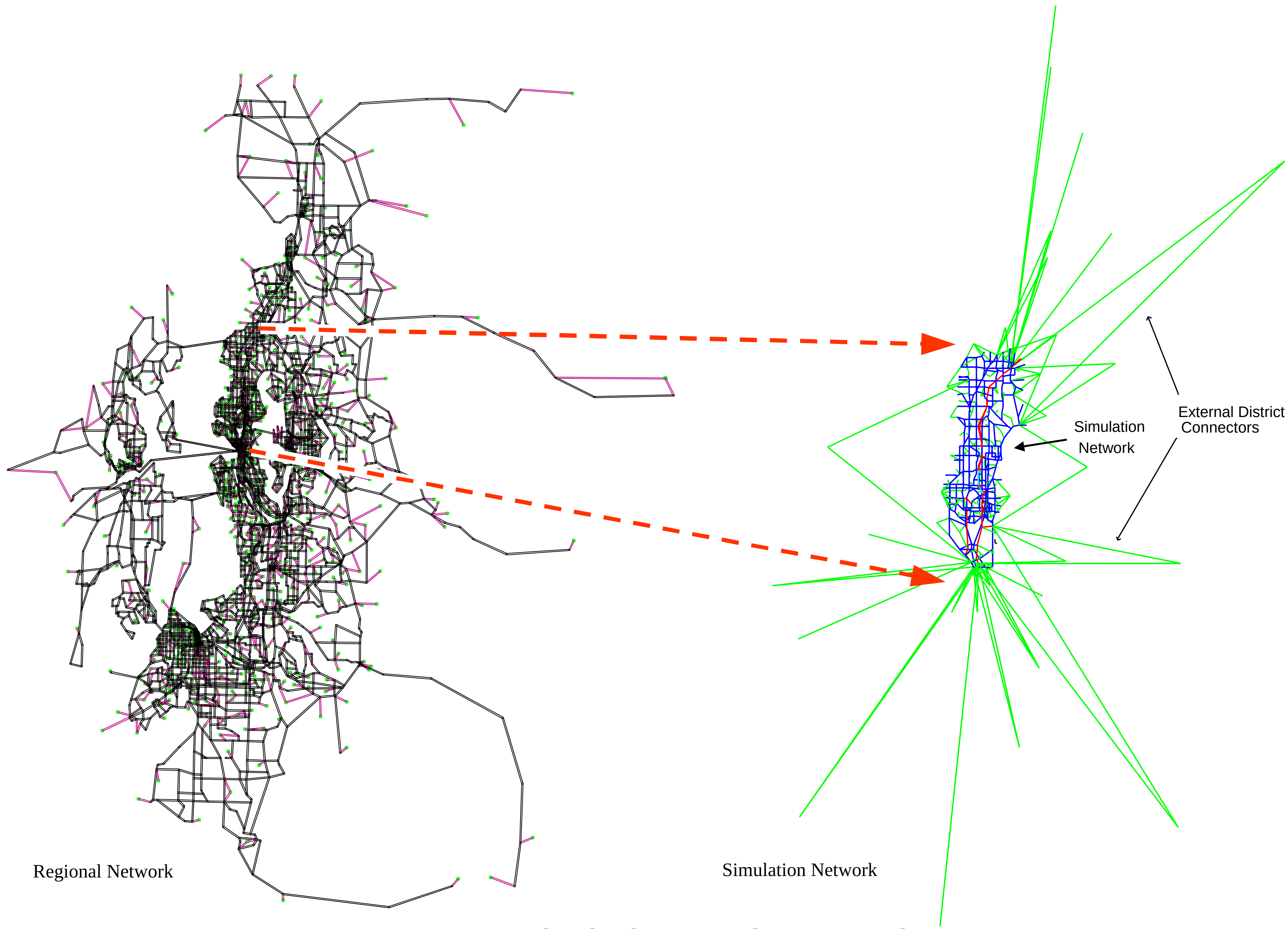

Figure 2.6 Regional and Subarea Simulation Networks

A summary of the development of these networks and their characteristics follows.

As shown in Figure 2.5 the regional forecasting system represents the travel in the four counties of the PSRC region (King, Snohomish, Pierce, and Kitsap). This area is represented using 832 internal traffic analysis zones and 18 external stations for a total of 850 zones. Within the simulation subarea the zones are the same as in the regional process (96 zones). It is very important to capture each person's complete trip from start to finish when examining the impacts of improved information (ATIS) in simulation. For the subarea simulation the entire 4 county model region is therefore maintained, however, as the distance from the simulation area increases the detailed regional zones are aggregated into 38 larger external districts. The subarea simulation uses 134 total zones to represent the region. Any trip that in the regional process goes to, from or through the simulation area is siphoned off and converted for input into the simulation process.

Figure 2.6 shows how the transportation network is also focused from the regional to the subarea simulation processes. The network within the simulation area should be the same for both the subarea simulation and regional modeling processes to minimize differences in results caused solely by inconsistencies in the transportation system's representation within each process. Consequently, the regional network coding was enhanced within the simulation area to meet the requirements of the simulation system. This enhancement included detailed coding of interchanges and the addition of new functional classifications and coding conventions to address ramp meters, HOV bypass lanes, limited access express facilities (SR99), and different types of HOV service (diamond lane, barrier separated, and arterial). The network coding modifications are described in detail in [2]. For each of the external district connectors the time and distance it takes to reach the simulation area from the external district in the regional model is coded.

Table 2.1 provides a summary of the network characteristics for both the regional forecasting model and subarea simulation networks used in the Baseline alternative. These networks provide the base upon which the Enhanced ITS alternative improvements are coded.

	Regional Network			Subarea Simulation Network		
Facility Type	Link Miles	Lane Miles	Capacity Miles	Link Miles	Lane Miles	Capacity Miles
Freeways and Expressways	1,139	2,418	4,038,991	76	220	378,645
Urban Arterials	1,360	2,192	2,285,944	278	494	525,305
Rural Arterials	5,355	6,604	6,857,640	182	279	281,707
Ramps	27	29	33,307	18	19	22,108
Zonal, External District Connections	2,112	4,151	4,296,674	2,271	4,542	4,542,380
Total	9,993	15,394	17,512,555	2,825	5,554	5,750,145

Table 2.1: Seattle MDI Baseline Alternative Network Characteristics

<u>Socioeconomic and Other Exogenous Inputs:</u> The demographic growth throughout the region; increase in external – internal and through trips; and change in special generators and other exogenous inputs, determine the trip generation and travel patterns that the transportation system must serve. The interrelationships between land use, transportation system congestion, and travel demand are complex and PSRC has a sophisticated feedback process to capture them, develop zonal level demographic data and trip generation, and to verify the results (see [22,23]). During

the summer and fall of 1998 PSRC was carrying out this process to update their estimates and current (1997/1998) data were not available. It was therefore decided to use the data that was available to create "Best Guess" estimates of the inputs required by the regional forecasting model.

One of the key inputs to the process is the zonal level growth in households and population. Households and their characteristics are the primary factors in determining the trips "produced" by each zone. While zonal level data was not available, PSRC had recently released population and household estimates for 1990 and 1997 by census tract for the four county region. A zone-to-tract table of equivalency was developed and the PSRC 1997 data merged with previously obtained 1990 zonal population and household estimates (Mitretek Seattle Case Study 1990 Validation [2]). This allowed new 1997 zonal population and household estimates for each zone to be derived. Table 2.2 provides a county level summary of the change for both population and households. As can be seen the region's households grew 13.24% in seven years. More significant were the high growth rates in the outer counties increasing commute distances and the stress on the commuter routes to the major employment areas. With the change in households, the distribution of income within each zone was assumed to remain the same from 1990 to 1997.

	Population				Households			
County	1990	1997	Change	% Change	1990	1997	Change	% Change
1. King	1,507,320	1,646,226	138,906	9.22%	615,055	674,597	59,542	9.68%
2. Snohomish	465,642	551,181	85,539	18.37%	171,618	203,837	32,219	18.77%
3. Pierce	586,203	674,309	88,106	15.03%	214,657	249,232	34,575	16.11%
4. Kitsap	189,732	229,585	39,853	21.00%	69,262	84,625	15,363	22.18%
Grand Total	2,748,897	3,101,301	352,404	12.82%	1,070,592	1,212,291	141,699	13.24%

1990 estimates from zonal level model demographic file "1990TAZF.WK1" (PSRC Oct. 1996)

1997 estimates from tract level "Population and Household Estimates" file "pop97.xls" (PSRC Sep. 1998)

Table 2.2: " Best Guess" Population and Household Trends

Employment by type is the primary factor used to determine the trips attracted to each zone. Employment is more difficult to track and estimate than other demographic data because of the many definitions of "employment" that are used by different data sources. Consistent definitions and data coverage must exist across data sets in order to analyze trends and develop new estimate. Consequently, even though there were PSRC 1997 estimates of employment covered under Washington State's unemployment insurance programs, consistent information for 1990 could not be found. The WSDOT Planning Office was able to provide a secondary data set of previously developed zonal employment information for 1990,1995, and 2010. This information was used to interpolate a set of "Best Guess" 1997 zonal employment estimates. These estimates and their implied growth from 1990 are shown in Table 2.3. As shown employment is also increasing at a rapid rate throughout the region and like the demographic growth is also concentrated in the outer counties. Employment grew 10.37% for the region from 1990 to 1997 which is slightly less than household and population growth.

	Employment				1990 to 1997	
County	1990	1995	1997	2010	Change	% Change
1. King	1,024,776	1,064,486	1,103,037	1,353,620	78,261	7.64%
2. Snohomish	176,750	197,974	207,904	272,453	31,154	17.63%
3. Pierce	235,759	261,027	269,523	324,750	33,764	14.32%
4. Kitsap	82,267	94,095	96,627	113,084	14,360	17.45%
Grand Total	1,519,552	1,617,581	1,677,091	2,063,907	157,539	10.37%

1990, 1995, 2010 estimaes from zonal level land use file "landuse.xlw" (WSDOT 1997)

1997 estimates interpolated from 1995 and 2010 estimates

Table 2.3: "Best Guess" Employment Trend from 1990-1997

The other significant determinant of transportation system use within in a region is the amount of travel that crosses its borders from “external” sources, or stations. This travel may either be occur to and from the region, or represent the trips through the area on their way to some other destination. To derive the growth in these trips the Average Annual Daily Traffic (AADT) count data was obtained from WSDOT for 1990, and 1993 through 1996. This information was used to make a “Best Guess” on the 1997 AADT for each external station. The 1997/1990 growth ratio was calculated. This growth ratio was used to expand the internal-external productions and attractions associated with each external station.

External stations			AADT From WSDOT Count Books							AADT Estimated	Ratio
County	TAZ	Location	1990	1991	1992	1993	1994	1995	1996	1997	97/90
Pierce	833	I-5 to Olympia	79900			86000	88000	90000	92000	94000	1.176
	834	SR-507 to Yelm	10100			12000	14000	14000	14000	14000	1.386
	835	SR-7 to Morton	3800			3800	4000	4100	4100	4200	1.105
	836	SR-706 to Longmire	1550			1700	1800	1800	1800	1800	1.161
	837	SR-123 S.of Cayuse Pass	810				845	730	883	910	1.123
	838	SR-410 E. of Chinook Pass	5600			5700	5800	6000	6000	6200	1.107
King	839	I-90 to Snoqualmie Pass	21400				26000		27000	27500	1.285
Snohomish	840	SR-2 to Stevens Pass	4259			4700	4700	4600	4700	4700	1.104
	841	SR-92 to Monte Christo	8900			9900	10000	11000	11000	11300	1.270
	842	SR-530 N. of Darrington	3400						3800	3866	1.137
	843	SR-9 N. of Arlington	1200			1500	1500	1500	1500	1500	1.250
	844	I-5 to Mt. Vernon	40000			45000	46000	48000	48000	49000	1.225
	845	SR-530 N. of Starwood								1.27 hh growth in 754 1.16 emp growth in 754	1.250
	846	SR-532 to Camano Island	11600			13000	14000	14000	15000	15700	1.353
	847	Mukilteo Ferry to Whidbey Island (SR 525)	5200			5900	6000	6300	6400	6500	1.250
Kitsap	848	Hood Canal Bridge (SR-104)	11424			13000	14000	14000	14000	14000	1.225
	849	SR-3 to Belfoir	11300				10000	10000	10000	10000	0.885
Pierce	850	SR-302 E. of SR-3	1850			1100	2000	2000	2000	2000	1.081

Table 2.4: External Station Traffic Growth

Through trips also travel through the external stations. They, however, cannot simply be expanded by the growth rate at each of their ends because this often leads to inconsistencies. If the external station at one end of the trip has a growth ratio of 1.5 and the station at the other end of the trip has a ratio of 1.1 they can’t both be consistently applied. Consequently, an “Iterative Proportional Fitting (IPF)” method was used to expand the through trips and maintain the external station growth rates as closely as possible (see [24]). This caused an increase in through vehicles trips from 5,203 in 1990 to 6,250 in 1997, a 20.12 % increase. This increase is on average consistent with the growth in external station volumes shown in Table 2.4.

The last updates to the exogenous regional model inputs made were the modifications to the special generator trips. Special generators are activity centers, or areas, which create trips and travel patterns very different from other areas in the region. The PSRC regional process treats the Sea-Tac Airport, Fort Lewis/Mchord, the Seattle Center, the Kingdome, and the Tacoma

Dome as special generators. For 1997/1998 one third of the change in trips from 1990 to 2020 was assumed. This is similar to the accelerated early growth during this period seen for trip generation overall. All of the other inputs, such as parking costs and transit fares were assumed to grow with inflation, or remain constant.

Best Guess 1997/1998 Baseline Travel: The socioeconomic, external station, and other exogenous inputs were used to develop the 1997/1998 estimates of trip productions and attractions by trip purpose which are then used to carryout the regional travel forecasting process shown in Figure 2.3. For each zone the productions for the Home Based Work, College, Home Based Other, and School trips were grown based upon the percentage change in households. The attractions for each trip purpose were grown based upon the change in both households and employment and their relative contribution in the PSRC trip generation formulas. The productions in each zone for the Non-Home Based and Commercial Vehicle trips were set equal to the attractions. Then for each trip purpose the attractions were "balanced" to the productions since for the region they must always be equal. The results of this "Trip Generation" Process are shown in Table 2.5. As expected, the overall growth in trips of 13.45% between 1990 and 1997 is similar to the growth in households.

	Daily Trip Productions And Attractions *			
Trip Purpose	1990	1997	Change	% Change
Home Based Work	1,813,125	2,062,372	249,247	13.75%
College	142,866	162,013	19,147	13.40%
Home Based Other	4,147,054	4,737,266	590,212	14.23%
School	203,805	234,969	31,164	15.29%
Non-home Based	2,854,087	3,239,356	385,269	13.50%
Commercial Vehicle	1,015,057	1,131,455	116,398	11.47%
Through (O/D format)	5,203	6,250	1,047	20.12%
Grand Total	10,181,197	11,573,681	1,392,484	13.68%

* After "balancing" trip productions equal trip attractions for each purpose

Table 2.5 Daily Trip Generation comparison, 1990 to 1997

Summary results of the Enhanced ITS (1997/1998) travel demand produced by carrying out the trip distribution, mode split, assignment, and feedback process are shown in Tables 2.6 through 2.8. Table 2.6 provides a summary of the daily person and vehicle trips by mode for 1990 and the Baseline. From 1990 to the Baseline there is a slight shift from transit to auto modes reflected by the lower growth in the transit trips. The transit trips grow at 2.48%. Within the auto modes there also seems to be a slight shift to non-carpool vehicle trips reflected by a 13.62% growth in these trips and only an 11.98% growth in carpool trips. These shifts are understandable given that the outer counties are growing at a much faster rate than the North Corridor. More trips are being produces in areas where the only option is auto and it is difficult to carpool.

Regional Travel: Daily Person and Vehicle Trips				
Measure	1990	1997 MDI Baseline	Change	% Change
Daily Trips				
Non-Carpool Vehicle trips	7,638,754	8,679,492	1,040,738	13.62%
Carpool Vehicle Trips	11,291	12,643	1,352	11.98%
Transit Person Trips	247,714	253,861	6,147	2.48%

Table 2.6: Daily Person and Vehicle Trip Comparison, 1990 to 1997

Similar trends are seen in the AM Peak Period travel shown in Table 2.7. The growth rates are slightly higher than for daily travel, however, transit and carpools are still growing at a less rapid rate than non-carpool vehicle trips. The AM Peak period was already congested and is only more so given a 14.06% growth from 1990 to 1997 shown in Table 2.7. This is especially true for corridors such as the North Corridor that are geographically bound, have increasing commuter travel through them, and have limited transportation capacity expansion options.

Regional Travel: AM Peak Period Person Trips By Mode				
Measure	1990	1997 MDI Baseline	Change	% Change
Non-Carpool	1,340,565	1,529,112	188,547	14.06%
Carpool	8,468	9,483	1,015	11.99%
Transit	70,571	72,504	1,933	2.74%

Table 2.7: AM Peak Period Person and Vehicle Trip Comparison, 199o to 1997

Once the regional travel process is carried out the trips to, from and through the subarea are siphoned off and fed to the subarea simulation analysis. Table 2.8 summarizes the 1990 and 1997/1998 Baseline trips that are provided to the simulation analysis. As shown the percent growth in regional vehicle trips is higher than those that go to, from, or through the simulation area. This is the result of two factors. First, the already mentioned growth in the outer areas will lead to relatively more of the vehicle trips being created there than in the simulation area. Second, the simulation area's facilities (I-5, SR-99, SR 522) were already congested in 1990. There is not as much ability to absorb additional trips without significant delays in the simulation area as there may be in other corridors, especially at bottlenecks such as the bridge crossings of the Seattle Ship Channel. In effect, diversion away from the North Corridor is taking place which creates latent demand for ITS and other improvements when they do occur.

AM Peak Period Regional & Simulation Area Vehicle Trips				
	1990	1997 MDI Baseline	Change	% Change
Regional SOV	1,340,565	1,529,112	188,547	14.06%
SubArea SOV	237,262	256,520	19,258	8.12%
% SubArea SOV	17.70%	16.78%		
Regional HOV	8,468	9,483	1,015	11.99%
SubArea HOV	2,059	2,230	171	8.31%
% SubArea HOV	24.32%	23.52%		

Table 2.8: AM Peak Period Simulation Area Trips Comparson, 1990 to 1997

2.8 1998 North Corridor Subarea Simulation Calibration

The development of the regional planning network for the 1998 time frame produces travel demand estimates for the AM Peak, and in particular, a demand pattern of travelers who utilize the North Corridor subarea. This travel demand pattern for the AM peak period in the subarea (corridor) was then converted for use in the traffic simulation. Time-variant modifications to the subarea demand pattern were calibrated to data describing trip time variability. This calibration exercise is important because if system variability is overstated, then benefits associated with adaptive control or ATIS will likely be overstated. Likewise, if system variability is understated, then the benefits of ITS technologies will likely be understated.

A key modification that has to be made to baseline travel demand pattern obtained from the regional model is the introduction of a time-variant, within-peak travel demand profile. The regional model assumes uniform travel rates between every origin and destination in the system over the 6:00-9:30 AM peak period. Mitretek, based on experience with calibrating the 1990 North Corridor model, had observed that a “peak-within-the-peak” period demand profile is more representative of the real world and is required to produce more realistic within-period travel time variation.

The primary data source for calibrating the within-peak travel time came from estimates of travel time delivered by the Microsoft Sidewalk service at regular intervals in the AM peak period over a 16 month period from June 1997 to October 1998 [12]. Estimated travel times between the Alderwood Mall and Mercer Street exits (both northbound and southbound) on I-5 were logged every 30 minutes in the 6:00-9:30 AM peak period. These two points are located near the northern (Alderwood Mall) and southern (Mercer Street) boundaries of the simulation subarea. Although this data is indicative of travel times only along the freeway and provides no data on arterial travel, the number of observations over the 16-month period provided sufficient data to characterize the variability along the most important facility in the North Corridor. A reduced sample set was selected from the raw data to remove days with missing or unreliable data points, as well as to eliminate any bias introduced by having collected data over two June-October periods. In all, 80 days of data were used to create the calibration sample set.

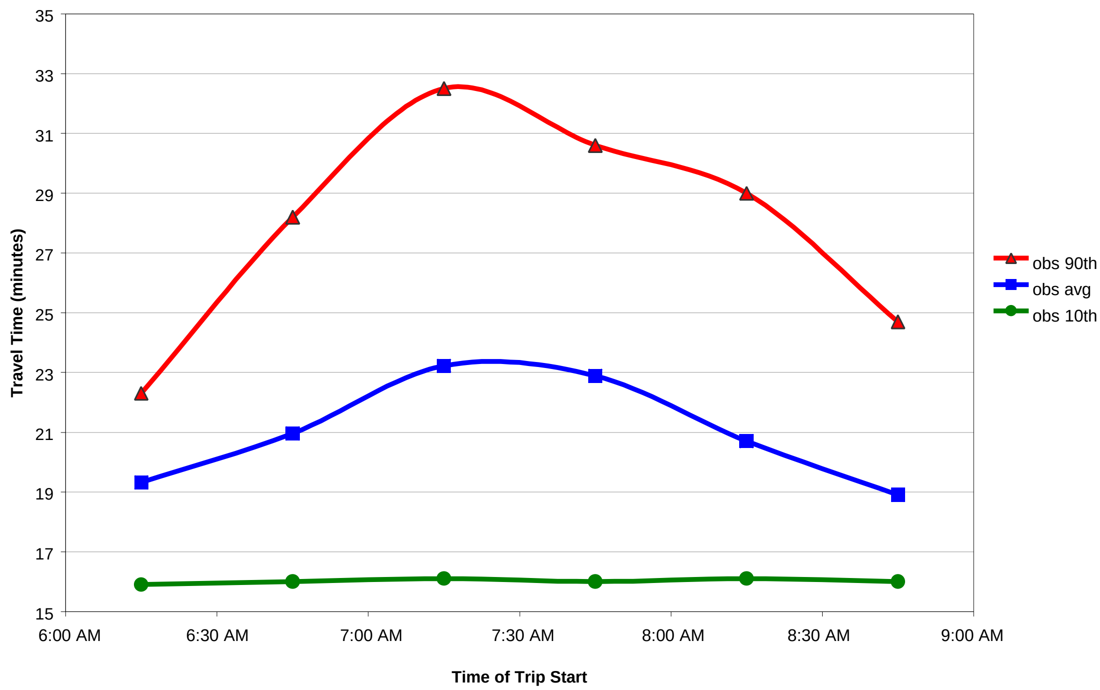

Figure 2.7 Calibration Data for Within-Day and Day-to-Day Variability (Seattle Sidewalk Estimates)

The calibration data for southbound (peak direction) travel between Alderwood Mall and Mercer Street on I-5 is illustrated in Figure 2.7. Average travel time between these two points (a roughly 14 mile trip) ranged from just over 19 minutes at the start of the peak period peaking to 23 minutes in the 7:00-8:00 AM period. This peak travel time then subsides, returning to a 19 minute trip at the end of the peak period (9:30 AM).

Other important calibration information can be generated from this travel time data set (illustrated in Figure 2.7). First, travel times in each period are rank-ordered from lowest-to-highest and a percentile analysis performed to quantify the variability of travel between the two points. At the 10^{th} percentile, representing uncongested conditions, there is no discernable peak and travel time remains flat at roughly 16 minutes. At the 90^{th} percentile, representing highly congested conditions seen for the trip during the year, travel time peaks to near 33 minutes in the 7-7:30 AM time period. Maximum reported travel time (not plotted) was more than 70 minutes.

The Sidewalk estimates are not as accurate as data provided from a dedicated probe-vehicle travel time study because they are based on link detector data. However, the travel time estimates were within 10% of travel times collected by Mitretek in a single-day experiment under relatively low-demand conditions using a GPS-based automated travel time collection device. Further experiments to test the accuracy under heavy-demand or incident cases were not possible given time and resource constraints. Although not a perfect measure, after some elimination of missing or unreasonable data, the data served its purpose of characterizing within-period travel-time variability for the calibration of the simulation model.

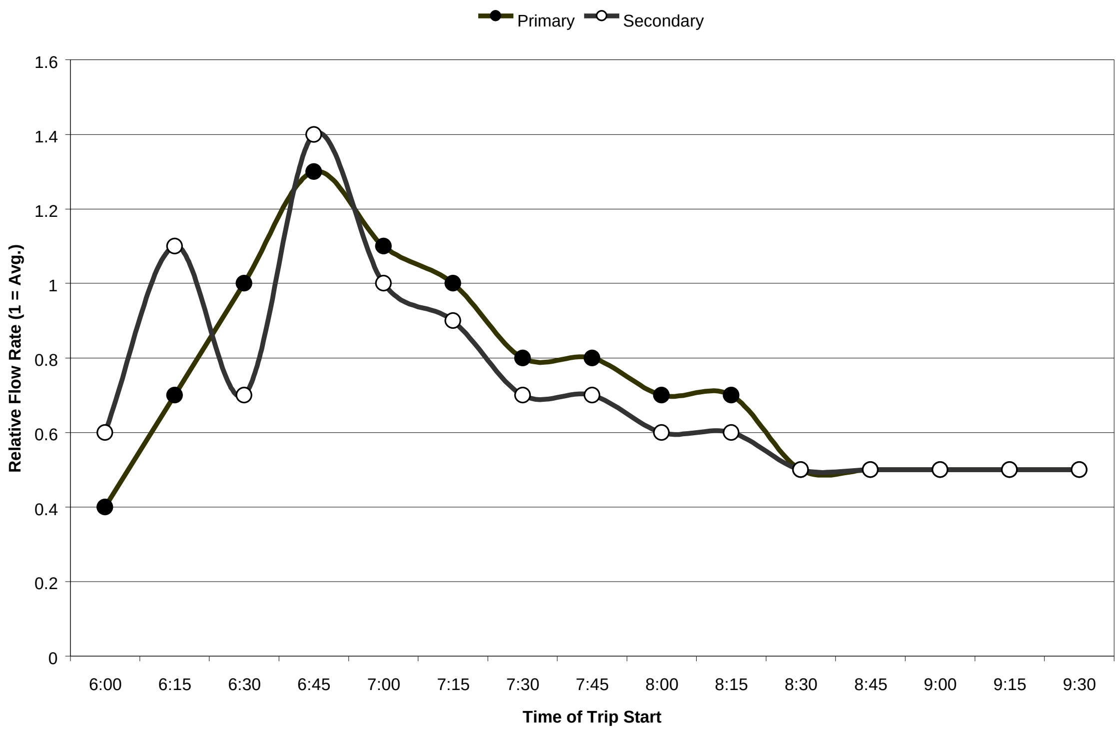

Figure 2.8 Primary and Secondary AM Peak Period Travel Demand Patterns

The precise timing and peaking of the travel demand pattern was the primary parameter used in the calibration of within-day travel time. A default peaking pattern was developed based on empirical data in the Highway Capacity Manual [3], and then adjusted to create a primary pattern for all origin-destination pairs. Application of this primary pattern in the training process (discussed above in Section 2.5) overloaded the freeway in the early peak period (6:30-7:00). Because of oscillation in the simulation multi-path route selection algorithm under the primary pattern, a modified pattern was applied for selected origin-destination pairs located directly along the I-5 facility. This secondary pattern satisfactorily compensated for the early-peak oscillation. The number of vehicles affected by this secondary pattern represent less than 5% of overall travel demand. The primary and secondary time-variant demand patterns are illustrated in Figure 2.8.

Although the calibration of within-day travel time in the training process is important in establishing reasonable habituated routings and travel time profiles, the calibration of day-to-day travel times requires a complete set of runs over the 30 representative day scenarios (described above in Section 2.3). In Figure 2.9, results from the analysis of the Baseline alternative are presented. For this analysis, four full AM peak simulation runs were conducted for each representative day scenario under different random seeds. From these 120 simulated days, average and percentile travel times can be calculated similarly to the analysis conducted on the

Sidewalk calibration data. In the case of the representative day scenarios, each scenario's contribution is non-uniformly weighted in contrast to the calibration data which weights each observed day equally.

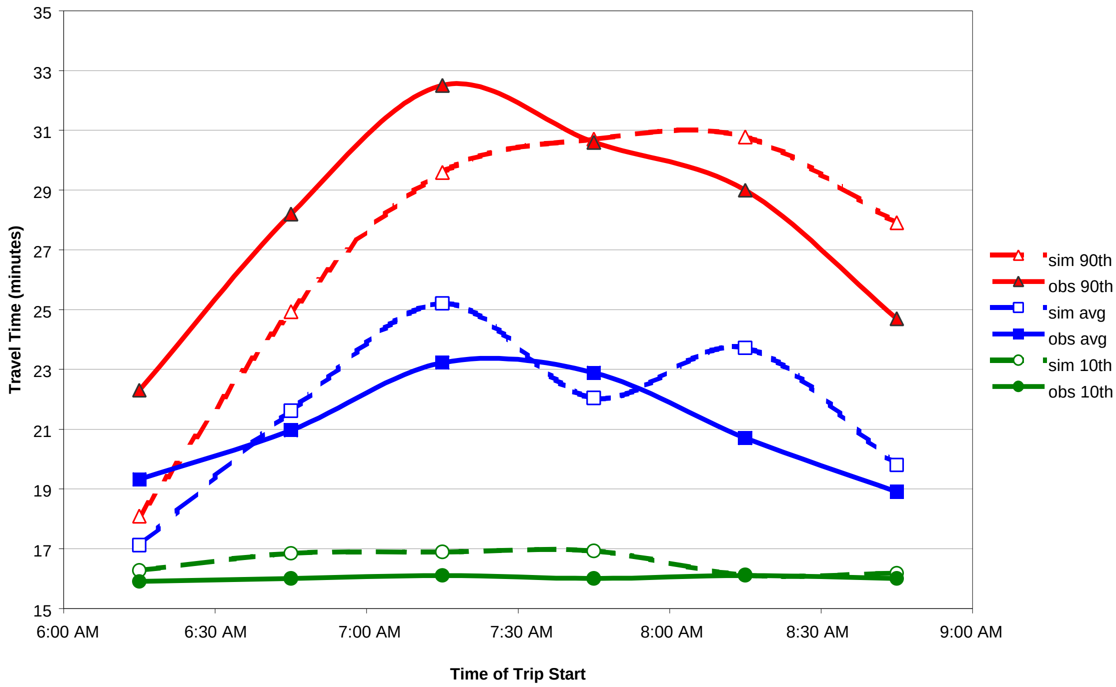

Figure 2.9 System Variability Calibration: Southbound I-5, Alderwood Mall to Mercer Street

Figure 2.9 illustrates that the variability seen in the calibration data and in the simulated data are quite similar. The calibration target data is again presented as in Figure 2.7 as the solid line with solid data symbols. Average travel time in the simulated data rises from 17 minutes to 25 minutes, peaking in the 7:00-7:30 AM period, then drops off to 19 minutes by the end of the AM peak period. Congested travel times at the 90th percentile peak at 31 minutes, while uncongested travel times range between 16-17 minutes. One may observe that simulated travel times in the 8:00-8:30 AM period is 1.5-2.5 minutes higher than the calibration data, and that the 90th percentile simulated data is lower in the early peak 7:00-7:30 AM period. Especially for the 90th percentile travel times here are strongly influenced by the timing and position of incidents along the I-5 freeway. This observation likely indicates that the incident profiles from 1993-94 had more, or more serious, accidents on the freeway later in the peak period than those occuring over the calibration data period, 1997-98.

The calibration of the network for within-day and day-to-day conditions is a critical factor in establishing the capability to assess ITS impacts using simulation. This effort for the Seattle MMDI network represents the most comprehensive and detailed large network calibration conducted to date for ITS impacts assessment.

SECTION 3: EXPERIMENTAL DESIGN

This section presents detail on the modeling experiments conducted in support of the Seattle MMDI effort. Section 2 presented the evaluation framework and the calibration of the Baseline case. Understanding the assumptions of the Baseline case is critical when examining the four MMDI-related experiments presented in this section. The first three experiments follow the three project groupings in isolation (ATIS, ATMS, and IMS/EMS) and the fourth examines these groupings deployed concurrently (Enhanced ITS).

The parameters selected in the Baseline case are considered the default values in any experiment where a set of control parameters is varied. For example, in the experiments isolating the impact of coordinated traffic signal control (ATMS), the Baseline parameter setting for various advanced traveler information usage levels (e.g., usage of web-based pre-trip planning services set to 0%) is utilized.

For the estimation of market penetrations for ATIS, precise quantification of actual usage rates cannot always be made. Model inputs generally do not accept ranges of values or allow for uncertainty in parameter estimation. In order to resolve this issue, Mitretek makes a reasonable estimate for all model parameters given currently available data. Where these parameters are used as controls within an experiment, a range of values is examined in a sensitivity analysis. While this effort does not more precisely quantify the parameter, it does indicate what range of impacts are associated in the area of uncertainty around a particular parameter choice.

As pointed out in Section 1.4, the majority of Seattle MMDI projects were focused on system integration or expansion, i.e., the connecting together of isolated capabilities or the incremental extension of existing technologies. Because of this, the Baseline case should not be misconstrued as representing a "No ITS" case, especially given the fact that the North Corridor itself contains a highly instrumented freeway segment (I-5) with advanced control and traveler information systems. In fact, many of these technologies have been in place for several years (e.g., ramp metering). With this in mind, the experiments have been designed to illustrate impacts of ITS after MMDI-related enhancements have been or could be implemented.

The "could be implemented" phraseology here refers to the fact that some projects enabled but did not enact a change in system control in the North Corridor. For example, the archiving of arterial data facilitated by the North Seattle ATMS (SE-1) allows WSDOT to comprehensively examine and test new traffic signal control patterns. To date, new plans based on the data have not been developed nor have jurisdictions along the arterial corridors agreed to implement a new plan. Again, the impact of these data-sharing capabilities were not implemented as a part of MMDI, but established a necessary condition for any future implementation. The ATMS modeling effort seeks to predict the potential impacts of implementing a new optimized signal control plan. In each experimental plan description, such projective assumptions are clearly itemized.

The "after" condition alternative, Enhanced ITS, represents a combination of improved ITS capabilities facilitated within the MMDI deployment time frame. These enhanced capabilities comprise the concurrent deployment of all enhancements examined in isolation as a part of the three sensitivity analyses. More specifically, these control parameters include an increase in users of detailed, real-time freeway travel-time information (ATIS), and a set of projective improvements to signal coordination (ATMS), and an improvement in existing incident management systems (IMS/EMS).

To date, we have not completed the planned ATIS and IMS/EMS sensitivity analyses. The results in Section 4 cover impacts over all scenarios using the default control parameters associated with the Baseline and the Enhanced ITS alternative. For ATIS, this implies a 6% market penetration for high-fidelity pre-trip traveler information. For the IMS/EMS analysis, this implies a 25% reduction in incident duration. The complete sensitivity analysis will be completed for the April 1999 final report.

3.1 Baseline Case Description

ITS Service Group	Relevant Baseline Infrastructure	Seattle MMDI Projects Represented in Enhanced ITS Alternative
Traveler Information Services (ATIS experiment)	Traffic reports on commercial radio, TV reports	Microsoft Sidewalk (SE-17) Etak/Seiko/Metro (SE-18) Fastline HPC (SE-19) Cable TV (SE-20) WSDOT Web Page (SE-26) Traffic Telephone (SE-27)
IMS/EMS Freeway Management (IMS/EMS experiment)	Shoreline TSMC freeway management capabilities, including ramp metering and VMS on I-5	Regional Video (SE-9) Incident Capture (SE-12) Incident Video (SE-13) Emergency Ops Center (SE-14)
Traffic Signal Control (ATMS experiment)	Fixed time-of-day plans	North Seattle ATMS (SE-1) Northwest TSMC (SE-7)
Transit Information Services	Static schedule information	King County AVL (SE-15) AVI Bus Signal Priority (SE-16) Riderlink/Busview (SE-23) King Co. Transit Display (SE-24)
Arterial Data Integration with ATIS	None	ITS Backbone (SE-29)

Table 3.1 North Corridor ITS Services in the Baseline Alternative

Table 3.1 summarizes the Baseline alternative. ITS deployments in the region have enhanced the scope and availability of traveler information services, freeway management, traffic signal control, and transit information services. Some of these enhancements predate the MMDI effort, some are unrelated to MMDI, some are MMDI projects. Some cases, like the WSDOT ATIS web site, are experiencing rapid growth in user base. Table 3.1 also shows how we have split up these capabilities into the categories of Baseline capabilities and Enhanced ITS capabilities.

Traveler Information Services. Incident, construction, and other emergency road closure information have been reported on radio, TV, variable message signs, and highway advisory radio for several years. Accordingly the use and operation of these advisory services is modeled in the Baseline alternative. Figure 3.1 shows the physical locations ([9]) of the VMS modeled as a part of the North Corridor subarea. The same signs are present in all experiments. The modeling of these devices is described in Section 3.2.

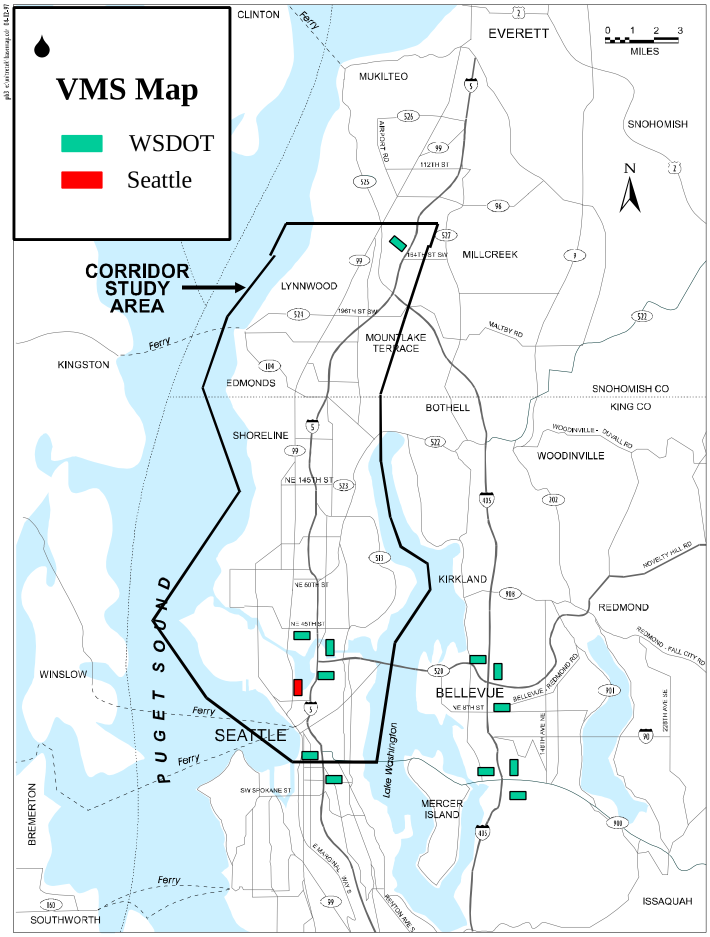

Figure 3.1 VMS Modeled in the North Corridor Subarea Model.

IMS/EMS Freeway Management. WSDOT has been operating an advanced freeway management system in the region for several years [10]. Most sections of the major freeways are instrumented with loop detectors every half mile in most sections and some sections with greater density. This data is communicated to the Shoreline Traffic System Management Center (TSMC) where it can be fused to provide a comprehensive picture of current regional traffic conditions, control ramp metering systems, and disseminate information through variable message signs, HAR, and Metro Traffic. We model these capabilities of the Shoreline TSMC in the Baseline.

In the subarea simulation current travel time information is only available for links assumed to be under surveillance. Surveillance devices in the North Corridor are either loops or CCTV cameras. Only CCTV equipped roadways or those equipped to send count data back to the TSMC are modeled as being under surveillance. Other roadways, such as those with only presence detectors that actuate traffic signals, are assumed to be without surveillance.

In the Baseline alternative we include only the surveillance infrastructure currently sending information to the Shoreline TSMC. Thus I-5, I-90, SR-99 south of 45th Street, the Evergreen Point Floating Bridge, the Lacey V. Murrow Bridge, and the Ship Canal Bridge are assumed to be under surveillance ([10]). All associated on-ramps are also assumed to be under surveillance. Figure 3.2 shows these surveillance assumptions on a map.

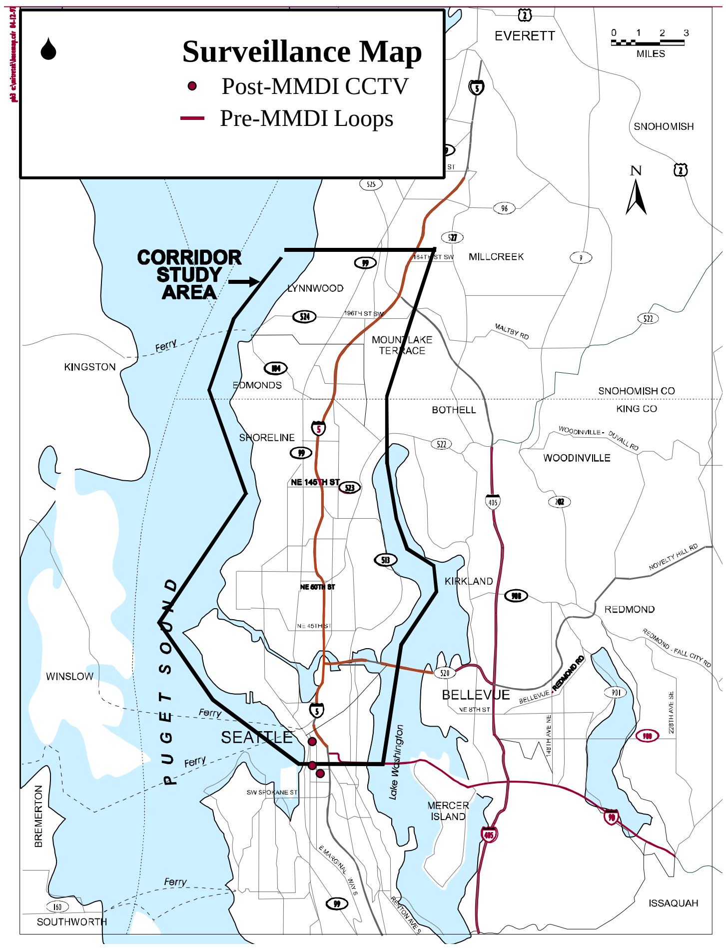

Figure 3.2 The North Corridor surveillance infrastructure map.

Traffic Signal Control. Signal control in the Baseline case is characterized as fixed, time-of-day control within jurisdictional boundaries [10,11]. Although simple actuation is a feature at some intersections, no adaptive control systems (like SCOOT) are present in the corridor. A FHWA-sponsored RT-TRACS adaptive control field test currently underway just outside the subarea in Bothell, WA is not considered as a part of either the Baseline case or the Enhanced ITS case.

Transit Information Services. The transit information category was chosen to analyze the possible impacts of dynamic transit information on transit ridership. BusView is a web-based application (http://flint.its.washington.edu/busview/) that allows a web browser to track buses on a map and view their current location relative to a bus stop. The Transit Watch project (SE-24) (http://www.its.washington.edu/buslink/) installs monitors at major transit use points that provide real-time estimates of the arrival time of the next bus. Relevant transit information facilites modeled in the Baseline is only static schedule information. As indicated in Section 1.2, impacts analysis of the transit grouping is not included in this document and no experimental plan is detailed in this section. The transit grouping may be assessed in the April 1999 final report based on budget and time constraints.

Arterial Data Integration with ATIS. The provision of real-time congestion information from major arterials to ATIS providers is not a feature of the Baseline case.

Section 3.2 Sensitivity Analysis: ATIS Experiment

Hypothesis: *Provision of traveler information containing more accurate, frequently updated quantitative freeway travel time estimates improves throughput and efficiency.*

Characterization and Data Sources: The ATIS experiment highlights the impact of several internet-based mobile and desktop information sources. Traffic information is also now available through Microsoft's Seattle Sidewalk website (http://trafficview.seattle.sidewalk1.com/), WSDOT's public website (http://www.wsdot.wa.gov/), a message watch sold by Seiko, and a handheld personal computer (HPC) sold by Fastline (http://www.fastline.com/).

In addition to these internet-based services, the University of Washington provides improved traffic information on cable TV (channel 27). The web-based services, cable TV, and the Fastline HPC currently provide maps of the regional freeway system. The freeways are color coded to reflect current congestion levels. The levels are estimated from flow and speed data obtained every 20 seconds through WSDOT's extensive freeway surveillance infrastructure. The web sites also provide views from more than fifty CCTV cameras, as well as incident and construction reports. The Seiko message watch provides only incident reports. The reports are encoded in a particular numeric format that must be known by the user.

Table 3.2 states the key attributes and corresponding descriptors that categorize the information services. Both the availability of field data and the modeling capabilities of EMME2 and INTEGRATION inform our choice of key attributes.

Key Attribute	**Descriptors**
Access type	*Pre-trip/En-route*
Congestion Information Quality	*High fidelity: quantitative, regional LOS or travel time* *Low fidelity: qualitative, localized congestion information*
Facilities covered	*Freeways only/Freeways and state routes only/ All roads*
Incident Reports	*Yes/No*
Construction Reports	*Yes/No*
Update frequency	*Time in minutes*
Usage	*Percentage of travelers*

Table 3.2 Differentiating Traveler Information Services.

Access type is significant because some traveler information sources can be accessed only at the point of origin (denoted by pre-trip), e.g., TV reports, whereas others can be accessed during the trip, e.g. radio. Therefore the access type of the information source used by a driver determines the propensity of the driver to re-route during a trip. Congestion information quality is perhaps the most important factor distinguishing the newer information sources included in the ATIS experiment from the older sources modeled in the Baseline. Sources with low fidelity congestion information quality tend to restrict themselves to reporting incidents, construction, and special events and some limited description of the congestion in the neighborhood of the incident. The high fidelity sources on the other hand provide visual displays of travel conditions in the system as a whole, thereby allowing the user to more effectively gauge the likely travel time for the entire trip. The information sources also differ in terms of the roadway facilities they report about. We refer to this as coverage. High fidelity congestion information from Cable TV and the web-based services is currently restricted to the freeway system only. The low fidelity information sources providing incident, construction, and event reports cover the freeways and all the state routes in the region. Most of the high fidelity information sources also provide incident reports. Table 3.3 classifies all traveler information sources by access type, congestion information quality, and coverage.

The classification in Table 3.3 is based on data gathered from different traveler information sources. Mitretek collected limited primary data ([12]) to understand the characteristics of some of the information sources. In particular we monitored the WSDOT web page, KIRO710 FM real-time web radio, and traffic telephone during the AM peak period on five weekdays. The data collected was analyzed to estimate the operating characteristics of the different sources. The impressions so formed were then compared with information obtained from WSDOT ([13]). The two sources of data were in agreement on all major points. We also visited Metro Traffic in the city of Seattle to better understand the process of generating radio traffic reports. Operating characteristics of the Seiko Message watch were obtained from ([14]).

	Low Fidelity Information	**High fidelity Information**
Pre-trip Access	Traffic Telephone TV Reports *Coverage: Freeways and state routes*	Desktop: WSDOT web Desktop: Sidewalk Cable TV Map *Coverage: Freeways*
En-route Access	Traffic Telephone (Cell) Radio, VMS *Coverage: Freeways and state routes.*	Fastline HPC Seiko Message Watch *Coverage: Freeways*

Table 3.3 Classification of traveler information sources

Two other features of the information sources that are important to the PRUEVIIN models are the dynamic responsiveness of the information and the usage of the source. The dynamic responsiveness of the information source is modeled by the interval at which it is updated. Most of the high fidelity sources are updated faster than every two minutes ([13]). These sources derive their information from WSDOT's freeway loop data that sends new counts to the TSMC every 20 seconds. The different high fidelity information sources process and package this data in different ways to make it suitable for users. Incident information is derived from reports created by highway patrol, WSDOT operators monitoring CCTV cameras, and individuals calling Metro Traffic. Radio traffic reports are typically broadcast every 10 minutes ([11,13]), traffic telephone recordings are updated at a comparable frequency, VMS signs and the Seiko watch are event-driven, reporting incidents as and when they occur ([15]). Table 3.4 summarizes the update intervals.

ATIS Service	**Reports**	**Update Interval**	**Usage**
WSDOT web	Incident: Yes Construction: Yes	< 2 min	300,000 hits per day (1998) 0.5 % of commuters (1997)
Sidewalk	Incident: Yes Construction: Yes	< 2 min	Unavailable
Cable TV	No	< 2 min	Unavailable
Fastline HPC	No	< 2 min	Low
Seiko watch	Incident: Yes	As needed	Low
Radio	Incident: Yes	10 min	49 % of commuters*
TV reports	Incident: Yes Construction: Yes	10 min	16 % of commuters
Traffic telephone	Incident: Yes Construction: Yes	5-10 min	Low (< 500 calls in AM peak)
VMS	Incident: Yes Construction: Yes	As needed	20% of commuters
HAR	Construction: Yes	As needed	49 %*

*HAR, commercial radio rates cumulative

Table 3.4: Classification of Seattle MMDI Traveler Information Sources

Table 3.4 also summarizes the usage data ([16,17,18]). At the time of this report, Microsoft is not sharing data on usage of the Seattle Sidewalk website. The cable TV traffic channel has been recently deployed and some survey data on its usage should be available in the near future. There are probably a few (less than 100) message watch users in the region. Thus its current or projected near-term impact is expected to be quite small. The current market penetration of the Fastline HPC is also small. Available data indicates that weekday AM traffic telephone call volume is less than five hundred calls per AM peak period. Since there are over 250,000 travelers in the North Corridor AM peak period the impact of traffic telephone may also be expected to be small. Small system-level impacts are difficult for discern above background randomness in a large simulation model like the North Corridor network. As a rule of thumb, the North Corridor simulation model requires at least a roughly 1% market penetration to generate a statistically significant impact.

During meetings with WSDOT and Batelle in September 1998, Mitretek learned that web usage data collection systems have been installed by WSDOT. The web usage numbers in Table 4 are preliminary findings. More detailed breakdowns of these numbers by day, time, kind of information accessed, user type, etc., will be available in the near future. The usage seems significant enough to measurably affect traffic flow in the region. Moreover, its usage seems to be growing rapidly. The radio, TV, and VMS usage data is obtained from [16].

Control Parameters: The subarea simulation supports the concurrent use of multiple driver and device classes that differ in their travel time information sources and routing algorithms ([19]). To model the operation of the North Corridor when loaded by drivers having different sources of information and access to different infrastructural facilities such as HOV lanes or VMS signs, we create five driver and two device classes (discussed later) as follows.

- Drivers without dynamic information (Class 1,2,3)
  - ◊ Class 1 (SOV commuters): Route themselves by habitual path determined during network training/calibration process (see Section 2.5).
  - ◊ Class 2 (HOV commuters): Route themselves onto the minimum travel time path, including HOV lanes, by historical information.
  - ◊ Class 3 (Unfamiliar drivers) : Route themselves via imprecise estimation of travel times based on roadway class.
- Drivers with dynamic pre-trip information (Class 4,5)
  - ◊ Class 4 (Low fidelity): Route themselves at the origin by incident reports and historical information.
  - ◊ Class 5 (High fidelity): Route themselves at the origin by flow map, incident reports, and historical information.

Table 3.5 describes the percentage of total AM peak period demand assigned to each driver class. The PSRC panel survey [16] indicates that 16% of the commuters watch TV reports prior to their morning commute. Since this is pre-trip low-fidelity information we assign this percentage to class 4 in the Baseline alternative. Although table 3.3 indicates that traffic telephone is also pre-trip low-fidelity, field data indicates that its usage may be neglected without appreciable error. Thus the remaining 84% of drivers are assigned to classes 1, 2, and 3 in the Baseline. The new class of drivers in the Enhanced ITS alternative is class 5.

The biggest component of class 5 population is estimated based on usage of the WSDOT and Sidewalk web pages. The PSRC panel survey ([16]) indicates that web page usage prior to the morning commute is of the order of 0.5 %. However, WSDOT published data ([18]) indicates usage of this service is rapidly growing, including a reported hit rate of 300,000 hits per day. If We assume that this figure is valid for normal weekdays and one-third of the hits occur during the weekday AM peak. At a rate of 2 hits per traveler, these 100,000 hits represent a population of 50,000 travelers. Further, the trips through the North Corridor represent roughly one-sixth of total travel in the region, so we estimate just over 8,000 travelers in the North Corridor AM peak utilize the WSDOT web page (a roughly 3% market penetration). Another equally large group (3% of travelers) is assumed to be looking at data pre-trip either on the Cable TV station or through Microsoft Sidewalk site.

Thus, in the absence of more detailed user statistics we assign the estimated 6% to class 5 in the ATIS experiment. A wider range of usage percentages will be conduced in follow-on sensitivity analyses. We have also assumed that the 6% in class 5 are drawn predominantly from the low-fidelity pre-trip information users and less from those who use no information at all, i.e., classes 1, 2, and 3 (see Table 3.5).

	Class 1	Class 2	Class 3	Class 4	Class 5
Baseline	84 %			16 % (TV)	0%
Enhanced ITS	84 %			10% (TV)	6 % (web)

Table 3.5: Percentage of Total AM Peak Demand by Driver Class

Since drivers of all classes may have access to information from VMS signs or radio en-route we define two device classes. At specific nodes in the network, drivers of all classes probablistically respond to radio congestion reports (Device class 1) or VMS alerts (Device class 2) for a specified period of time (see figure 3.3). Both devices are assumed to provide low fidelity information. Accordingly, during the period of influence drivers are assumed to route themselves onto the minimum travel time path based on their experiential travel time data and a large delay associated with the advisory alert. The two device classes differ in the following respects. Class 1 devices are only modeled on links that physically correspond to a roadway with a VMS sign on it ([9]). Class 2 devices are modeled as being present at all nodes since there is total regional radio coverage. Furthermore probability of response is class specific and denoted by Pradio and Pvms respectively.

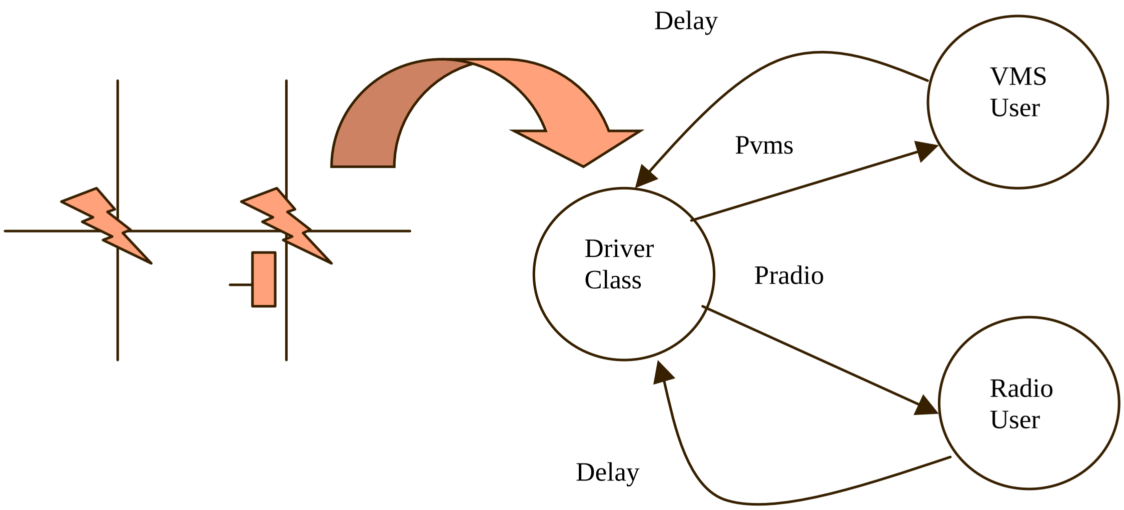

Figure 3.3 Response to Device Classes

The number of responders is calibrated to results of the PSRC panel survey [16]. The probability Pvms is chosen so that 20% of the drivers in the AM peak period respond to VMS alerts at least once during a calendar year. Likewise the probability Pradio is chosen so that 49% of the drivers become radio listeners at least once in the same time frame. In each scenario run, the simulation reports the number of responders by origin-destination pair. Annual usage data is calculated by first finding the maximum number of responders over all scenarios for each origin-destination. These maximums are then summed over across the range of origin-destination pairs in the demand pattern.

Since driver and device classes differ in the type of information used for routing, it is important to model the distinctions between historical, roadway class, low fidelity, and high fidelity information in INTEGRATION. All information used for routing in INTEGRATION is in the form of time slice specific link travel time vectors. Table 3.6 describes the distinctions between the different kinds of information.

Information type	Travel time model
Roadway class information	Freeflow link travel time (LTT).
Historical information	LTT vectors by time slice generated by the training process.
Low fidelity information	Historical travel time for non-incident links Large travel time values for incident links.
High fidelity information	Historical travel time for links without surveillance. Current travel time with random error for links with surveillance.

Table 3.6 Modeling Information Quality

In the case of low fidelity information, the large travel time value on the incident links is chosen to route the driver class away from the incident link and onto reasonable alternative paths. In the case of high fidelity information the travel time used for routing is assumed normally distributed with the mean set at the current link travel time and a coefficient of variation of 10%.

Under these conditions of enhanced ATIS capability, 120 individual simulation runs (30 scenarios x 4 random seeds) were conducted. Travel time and throughput of the system is then compared against the travel time and throughput characteristics of the Baseline case. Results of this experiment are presented in Section 4.1.

3.3 Sensitivity Analysis: ATMS Experiment

<u>Hypothesis</u>: *Improvements in arterial signal coordination from jurisdictional cooperation and more detailed data on queue size improves throughput and efficiency.*

<u>Characterization and Data Sources:</u> Within the North Corridor subarea there are 135 major signalized intersections as well as a much larger number of additional intersections controlled by traffic signals. A major intersection is defined as the intersection of two facilities represented in the regional planning model. Based on data taken from the North Seattle ATMS document and interviews with WSDOT staff [11], we characterize the Baseline traffic signal control in the North Corridor as fixed, time-of-day control.

Fixed refers to plans developed by the controlling jurisdiction, based on average peak or off-peak demand, that cannot be changed in real-time. In some cases, these plans may be updated as often as monthly or quarterly, however they are not changed based on 15-minute or 30-minute updates of arterial queue lengths or other link performance metrics. No adaptive control is modeled in the Baseline, although simple actuation is a feature at some intersections. Time-of-day indicates that for high-volume arterials, there is often a morning and evening peak plan rather than a generic peak period plan. Typical cycle lengths, phase splits and other data in the area are taken from the North Seattle ATMS document.

Two important arterials in the subarea are SR99 (running parallel to and just west of the I-5 freeway) and SR522 (carrying traffic from the northern edge of Lake Washington to its southern terminus with I-5). These arterials are of significant length and both pass through several jurisdictional boundaries where the responsibility for setting timings changes. Within the North Corridor subarea, SR99 has three such boundaries, SR522 one. In the morning peak period, signals along these two arterials are generally timed for speed limit progression. Some exceptions occur by jurisdiction. Although an exhaustive analysis of signal plans was not undertaken, this characterization of the timing plans is supported by a series of GPS-floating car travel time runs collected along SR99 by Mitretek in 1997.

<u>Control Parameters</u>: Three distinct effects of a projective North Seattle ATMS signal retiming project are modeled in the simulation as a part of this experiment:

1. The impact of coordinating signals at major intersections from "top to bottom" along SR99 and SR522 without regard to the current jurisdictional boundaries.

2. The coordination of minor signals along these same corridors at progression speeds selected between major intersections.

3. The calculation of progression speeds between major intersections based both on speed limit and average queue length measured at each approach to a major intersection.

<u>Major Intersections/Progression Speeds</u>: The North Corridor simulation network models 135 major arterial intersections. A single node connecting at least two roadway segments models each of these intersections. The version of INTEGRATION employed for this effort is meso-scale and correspondingly does not explicitly model lane position or gap acceptance. INTEGRATION does however, model cycle length, phase split, and offset for each approach to an intersection. In addition, detailed tracking of turning movements are not directly modeled. Other aspects not directly modeled include turn pocket length, gap acceptance for permissive left hand turns, and permitted left-hand turn phases. Signal plans developed within the North Corridor model must therefore be viewed within the limitations of the model to represent those plans. While the details of individual intersections are not directly modeled, there is explicit representation of signal coordination along a corridor.

Thus, using the offset characteristic in the signal control model, the analyst may examine the effectiveness of linking strings of intersections at various progression speeds. In the ATMS case, we assume that a traffic engineer developing a "top-to-bottom" coordination of SR99 and SR522 would have access to an extensive database of AM peak queue lengths along these corridors. This data, heretofore unavailable, would allow our hypothetical engineer the ability to set signal offsets so that standing queues at intersections would be in motion by the time the first platoon of vehicles from an upstream intersection arrived.

Minor Intersections. There are also a great number of minor signalized intersections on the ground in Seattle, Lynnwood, and in other jurisdictions of the North Corridor subarea. These minor intersections do not have corresponding intersections in the regional model database obtained from the PSRC. Coordinating these minor signals, however, will provide improved throughput and/or improved travel time along our major arterial corridor. Improvements of this type are modeled indirectly through adjustment to link parameters within the subarea simulation network. For example, stretches of SR99 have a number of minor signals allowing access to commercial development along its length. Many of these lights are already coordinated with respect to mainline speed limit progression. The amount of adjustment to these link parameters is adapted from a previous Mitretek modeling studies examining the relationship between signal density and benefit of coordination. [2,20]

Baseline Signal Timing Plan: SR99 and SR522. In the Baseline case, an initial comprehensive signal plan was implemented. Where data specific to traffic signal control could not be obtained, Webster's formula for isolated intersections based on approach volumes under average travel demand was applied to set cycle length and phase split. Speed limit progression was then implemented along 14 major arterial corridors, including SR99 and SR522. Breaks in this signal coordination were implemented at jurisdictional boundaries for SR99 and SR522 and calibrated using floating-car data collected in the AM peak. No improvement to link capacity or free-speed is coded for improvements to minor intersection signal coordination. The resulting signal plans for SR99 and SR522 are shown in Tables 3.6 and 3.7, respectively.

Intersection with SR99	**Offset at Speed Limit Progression (seconds)**
188th St. SW	0
SR524	*0*
212th St. SW	105
220th St. SW	44
76th Ave. W	88
238th St. SW	9
185th St.	44
175th St.	*0*
155th St.	96
145th St.	*0*
Roosevelt Way N	14
130th St.	96
105th St.	110
85th St.	105
Green Lake Dr. N	3
80th St.	28
W. Green Lake Dr.	64

Table 3.6 Baseline SR99 Major Signal Coordination

Intersection with SR522	Offset at Speed Limit Progression (seconds)
Ballinger Way	0
155th St.	110
150th St.	0
145th St.	27
125th St.	54
15th Ave. N	69
80th St.	27
Roosevelt Way	42

Table 3.7 Baseline SR522 Major Signal Coordination

ATMS Experiment Signal Timing Plan for SR99 and SR522. In the ATMS experiment, the signal-timing plan developed for the Baseline case was modified to reflect changes at major intersections. Rather than a "top to bottom" coordination at the speed limit, however, the average queue length seen at each approach is taken into consideration in the calculation of progression speed.

Average queue length at each intersection, although an important metric, does not precisely define the most effective progression speed. Across a 3.5-hour peak period, the average queue length may be realized precisely on approach only on rare occasion. In fact, if one considers a simple bimodal distribution, the average may actually never reflect a single observed data point. For this reason, Mitretek conducted a limited off-line optimization analysis isolating the performance of SR99 and SR522 varying the amount of delay allocated to each queued vehicle seen on average in the peak period.

Employing the simulation at average travel demand, clear weather, and no accidents in the system, a reduction in progression speed was tested for 0.0, 0.25, 0.5, 0.75, and 1.0 seconds per queued vehicle seen on an approach. Independent tests were performed for SR99 and SR522. Travel time top-to-bottom in each corridor was used to evaluate each plan. In the end, a delay allowance of 1.0 seconds for SR99 and 0.25 seconds for SR522 provided the most effective progression speeds.

The resulting signal plans for SR99 and SR522 are shown in Tables 3.8 and 3.9, respectively, based on a corridor-wide cycle length of 120 seconds.

Intersection with SR99	Offset at Speed Limit Progression (seconds)	Offset With Queue Release (seconds)
188th St. SW	0	0
SR524	62	101
212th St. SW	47	118
220th St. SW	106	16
76th Ave. W	30	118
238th St. SW	59	58
185th St.	75	38
175th St.	27	25
155th St.	24	37
145th St.	78	13
Roosevelt Way N	92	31
130th St.	54	113
105th St.	68	8
85th St.	63	4
Green Lake Dr. N	81	26
80th St.	106	51
W. Green Lake Dr.	22	89

Table 3.8 Enhanced ATMS SR99 Major Signal Coordination

Intersection with SR522	Offset at Speed Limit Progression (seconds)	Offset With Queue Release (seconds)
Ballinger Way	0	0
155th St.	59	68
150th St.	75	86
145th St.	102	0
125th St.	9	38
15th Ave. N	24	70
80th St.	102	48
Roosevelt Way	117	67

Table 3.9 Enhanced ATMS SR522 Major Signal Coordination

Minor signal coordination improvements were also implemented at the link level. Based on a previous Mitretek study of signal density and the impacts of coordination, changes to link free-flow speed, speed-at-capacity, and capacity are coded. These three parameters define a particular speed-flow relationship for each link in the meso-scale INTEGRATION simulation. Table 3.10 presents these link-level changes for SR99 and SR522. Note that links representing SR522 have a higher impact than for SR99 because of the higher density of minor intersections along SR522 relative to SR99.

Facility	Free-Flow Speed	Speed at Capacity	Capacity
SR99	3%	1%	1%
SR522	6%	2%	2%

Table 3.10 Link-level Modifications For Minor Signal Coordination

The ATMS sensitivity analysis is evaluated using 120 individual simulation runs (30 scenarios x 4 random seeds), and compared against the travel time and throughput characteristics of the Baseline case. Results of this experiment are presented in section 4.2.

3.4 Sensitivity Analysis: IMS/EMS Experiment

Hypothesis: *A reduction in incident blocking time improves throughput and efficiency.*

Characterization and Data Sources: In this experiment, we reflect system level impacts resulting from the ability of highway patrol, WSDOT, and emergency medical service providers to coordinate their response to incidents. The scenario set developed for the North Corridor contains a representative set of accidents and incidents. The details of this data set is detailed in Appendix B and provides information in incident location, onset and duration.

Reaction to an incident may be characterized by detection time, response time (time to getting the first unit to the incident site), and time-to-removal. In this experiment, we assume that there is no change from the current incident detection and response times of 4 and 6 minutes, respectively [19]. However, we do assume some reduction in incident duration because of increased coordination among responding agencies. Estimates in Seattle of such impacts are not currently available, however, we attempt to bracket this impact by using data from a similar study in Houston where a 25% reduction in incident duration was reported.

Control Parameters: Incidents occurring along I-5 or SR99 have durations reduced by 25%. See Appendix B for a listing of representative scenarios with incidents on these links.

Under these conditions of reduced incident duration, 120 individual simulation runs (30 scenarios x 4 random seeds) were conducted. Travel time and throughput of the system is then compared against the travel time and throughput characteristics of the Baseline case. Results of this experiment are presented in section 4.3.

3.5 Alternatives Analysis: Enhanced ITS

Hypothesis: Implementing the ATIS, IMS/EMS, and ATMS improvements concurrently improves system throughput and efficiency.

Characterization and Data Sources: The Enhanced ITS Alternative is a combination of the improvements made as a part of the ATIS, IMS/EMS, and ATMS experiments. Thus, it features an improved signal coordination system on SR99 and SR522, reduced incident duration from improved incident response coordination, and the introduction of the quantitative freeway condition data to pre-trip planners. However, this alternatives analysis is different than the three simulation experiments that precede it because it involves the full utilization of regional and subarea modeling in the PRUEVIIN framework. Because of the presence of the regional model in the analysis, travel demand in the corridor changes in response to improvements made to system capacity in the corridor.

Further, we model the impact of the ITS Backbone project to integrate arterial detector congestion data into the traveler information services assumed to be operating in the ATIS experiments. In the Enhanced ITS alternative we add surveillance on the rest of SR-99 north of Green Lake. South of Green Lake, SR99 is an expressway facility and is not assumed to be under surveillance. In addition, SR 522 between I-5 and Bothell is considered to be under surveillance. We assume arterial congestion data is presented in the same format and with the same reliability as the data from freeway detectors along I-5.

Control Parameters: Simulation parameters are set as in the ATIS, IMS/EMS, and ATMS experiments. Toggles controlling the provision of current travel time estimates to ATIS providers are switched to on for segments of SR99 and SR 522.

Travel demand in the corridor is slightly higher from a pre-feedback initial run of the regional planning model. A side experiment was conducted in the simulation model to estimate the effect of steady-state improvements to traffic signals along SR99 and SR 522. Based on these experiments, the following link-level improvements are made to the regional model, illustrated in Tables 3.11 and 3.12.

Component	Free Flow Speed	Link Capacity
Major Signal	2%	3%
Minor Signal	3%	1%
Total Impact	5%	4%

Table 3.11 Enhanced ITS SR99 Link-Level Improvements for Regional Model

Component	Free Flow Speed	Link Capacity
Major Signal	1%	0%
Minor Signal	6%	2%
Total Impact	7%	2%

Table 3.12 Enhanced SR522 ITS Link-Level Improvements for Regional Model

The results indicate that full coordination along SR99 from the current four segments to one unified segment is a more significant impact than unifying the two segments of SR522. Further, the relatively low density of minor signals on SR99 makes this component of lesser impact than the major signals. The situation is reversed for SR522, where the higher density of intermediate signals accounts for a larger share of impact than the corridor coordination. Note also that the impacts in the regional model differ from the parameters selected for the subarea simulation. This is because the simulation models the major signals explicitly. Impacts from minor signals are consistent in the two models, however.

When these link-level improvements (Tables 3.11, 3.12) are coded at the regional level, travel demand patterns redistribute themselves to take advantage of the improvements. Whereas there is no change to overall regional person-trips (assumed fixed), there are some changes in steady-state demand patterns, redistributing trips into the North Corridor subarea.

This change to regional trip patterns results in an overall increase of 0.42% in subarea travel demand. This represents the drawing in of around 1,000 vehicles into the North Corridor subarea. Travel is also slightly longer (0.38%) reflecting impacts within trip distribution at the regional level. The number of regional HOV and Transit trips drops slightly (-0.18%). Overall, regional travel demand may be characterized as a little longer, but little change in overall travel time.

The Enhanced ITS alternative is evaluated through 120 individual simulation runs (30 scenarios x 4 random seeds). Travel time and throughput of the system is then compared against the travel time and throughput characteristics of the Baseline case. Results of this experiment are presented in section 4.4. A second pass simulation analysis is planned for the Enhanced ITS alternative based on a complete feedback cycle with the regional model.

SECTION 4: RESULTS

This section presents preliminary results from the three sensitivity analyses (ATIS, IMS/EMS, ATMS) and the alternatives analysis (Enhanced ITS). Measures of effectiveness for the subarea simulation are calculated in both the sensitivity analysis and the alternatives analysis. Regional MOEs are calculated only for the alternatives analysis. Subarea MOEs are calculated from either trip-based data or link-based data.

Trip data is collected from all vehicles that begin trips in the network between 6:15 AM and 8:30 AM. For these trips, *delay reduction* is calculated as the difference between the travel time in each scenario and free-flow (30% of average demand, no accidents in the system, good weather) travel times. *Throughput* measures the number trips starting in our time frame that can finish before the end of the peak period at 9:30 AM. Delay reduction and throughput measures are calculated for each scenario. An annualized figure is then calculated by computing a weighted average of across all scenarios. Each scenario has a weight equal to its relative probability of occurrence (see Section 2.3). Delay reduction and throughput measures are displayed in this section with respect to the results obtained in the Baseline case.

System *coefficient of variation* is calculated by first examining the variation in travel times across all scenarios for each origin-destination pair. Next, an average system variation is then calculated by summing across all origin-destination pairs, weighted by the number of trips associated with the origin-destination pair. The square root of average system variation is then calculated to provide the standard deviation of average system travel time. This standard deviation is divided by the annualized mean system travel time to compute the coefficient of variation.

Link data is collected in the simulation regarding travel speeds and stops. Speed data is archived every 15 minutes of simulated time for every link in the network. Average travel speed observed in the simulation during the preceding time interval is logged. These link-speeds are then collected by facility type (freeway, expressway, arterial) over the network and logged weighted by link-length (kilometers). This is performed for each scenario and then summed for an annual average using the scenario weights. For comparison with the Baseline case, these speed profiles are then normalized by total vehicle-kilometers of travel in the system to create the statistic *percentage of vehicle-kilometers of travel by speed range*. A similar technique is applied to stops estimated by the simulation at a link level every 15 minutes. The *expected number of stops per vehicle-kilometer of travel* is the measure used in comparison with the Baseline case.

4.1 ATIS Experiment

Overall, the ATIS experiment indicates that the improvements modeled have limited but positive impact on system performance. This improvement is highest in scenarios where the network is experiencing a combination of heavy demand and freeway accidents. One observation that can be made is more precise freeway congestion information is consistently helpful to certain O-D pairs in the system. These are not the long freeway-based trips usually associated with ATIS but mid-range trips (18-25 km) within the subarea that cross I-5. An example of such trip is from Edmonds to the University of Washington southeast across the corridor. These travelers can access I-5 at several exits or bypass it altogether when choosing from a set of relatively competitive alternative routes.

For the ATIS-related sensitivity analysis, both system impacts and travel impacts on users and non-users of ATIS are tabulated. Section 4.1.1 presents the system-level impacts, while Section 4.1.2 presents a comparative analysis of travel characteristics of the various traveler classes modeled in the subarea simulation.

4.1.1 System Impacts

<u>Delay Reduction</u> (Figure 4.1). Statistically significant impacts can be observed for the EG1 and the HD1 scenario. The EG1 scenario features 9% higher-than-expected demand and a major incident on I-5. HD1 features a number of smaller accidents and 21% higher-than-expected demand. On an annual basis, delay is reduced by 0.07 minutes (4.2 seconds) per traveler. This represents a annualized system delay reduction of 1.5% compared to the Baseline case.

<u>Throughput</u> (Figure 4.2). Statistically significant impacts on throughput are observed for scenario EW7. This scenario features 20% lighter-than-expected travel demand, rain, and twelve accidents in the system. On an annual basis, throughput is improved by 0.02%, corresponding to roughly 30 additional vehicles completing trips in the peak period over the Baseline case.

<u>Coefficient of Variation</u>. The Baseline case coefficient of variation is 0.2269. Applying this to a trip with an expected duration of one hour, a traveler would have to budget 1.2269 hours (73.6 minutes) to arrive at his/her destination on-time two-thirds of the time. The value obtained in the ATIS experiment is 0.2248, indicating that travel has become slightly more predictable across the system. Under the constraints of our hypothetical one-hour trip, the amount of time needed to budget to be on-time two-thirds of the time is 73.4 minutes.

<u>Percentage of Vehicle-Kilometers of Travel By Speed Range</u> (Figure 4.3). The impact on facility speeds is small and indeterminate in nature. Some increase can be observed in high-speed freeway travel (50-60 mph), but similar increases can be seen in lower seed freeway travel as well (20-30 mph). These differences are likely smaller than the inherent randomness in the simulation.

Expected Number of Stops per Vehicle-Kilometer of Travel (Figure 4.4). A small improvement in stops can be observed for freeway travel. The amount of travel occurring in the system with fewer than 0.25 stops per kilometer increases by roughly 9 percent. Impacts on non-freeway facilities are negligible.

4.1.2 User Impacts

At this stage, only first-level tabulation of user impacts have been completed. Subarea travel time for high-fidelity pre-trip ATIS have travel times that are roughly 0.2 minutes faster than average baseline travel time (18.9 minutes versus 19.1 minutes). One interesting observation is that low-fidelity travelers have slightly worse travel time performance than information non-users (19.4 versus 19.1 minutes). The poor performance of the low-fidelity respondents may be indicative of travelers making route choices under high uncertainty. An example of this is unwarranted freeway-to-arterial diversion when a minor freeway accident is reported on commercial radio.

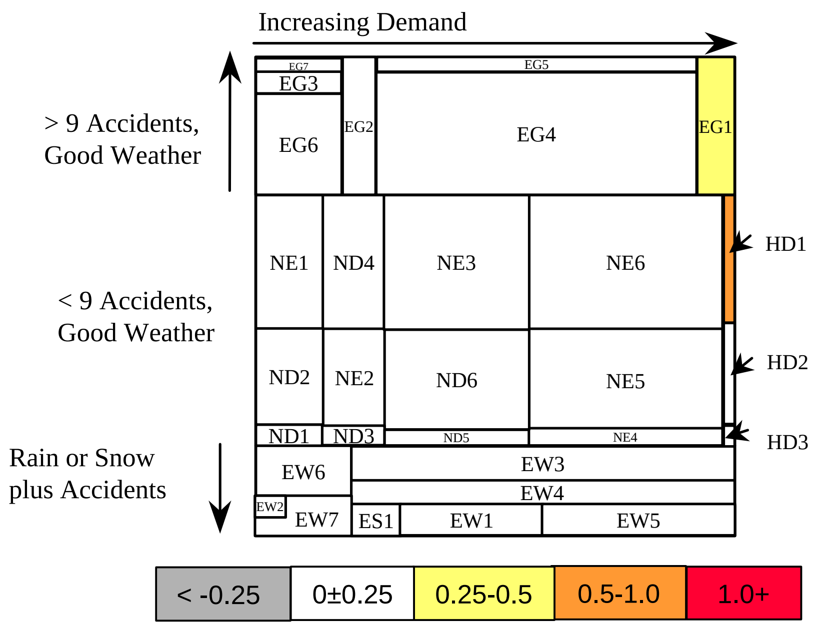

Figure 4.1 Minutes of Delay Reduction: Baseline vs. ATIS

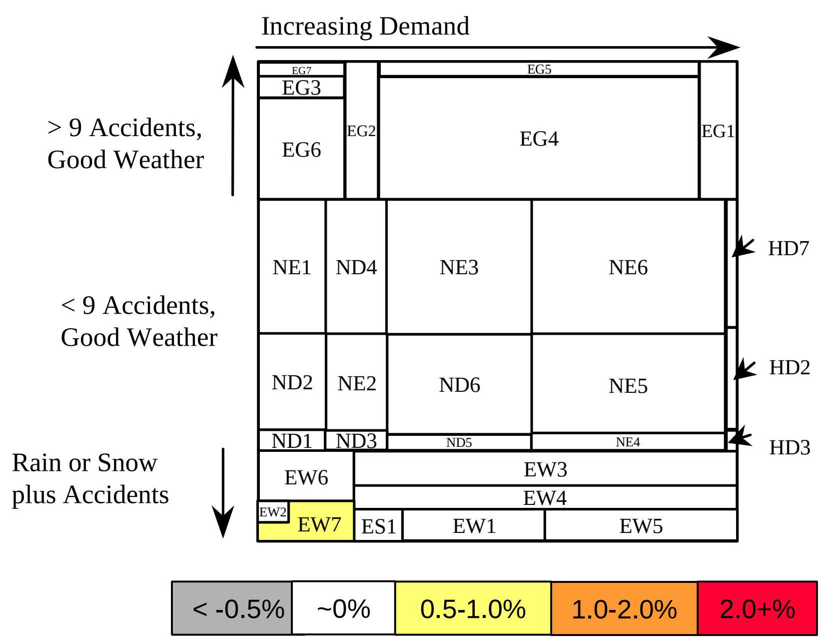

Figure 4.2 Increase in Vehicle Throughput: Baseline vs. ATIS

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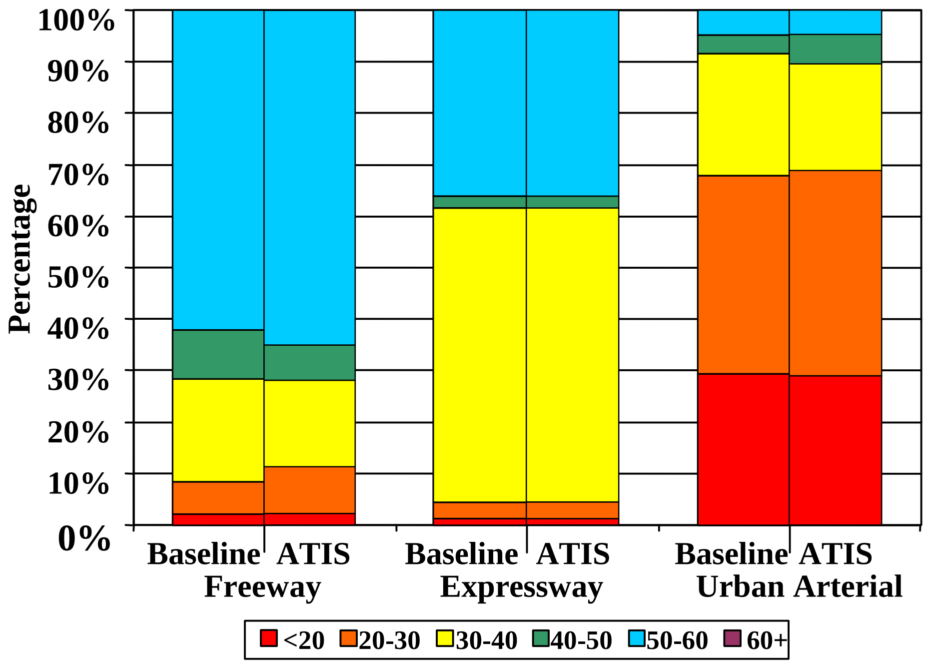

Figure 4.3 Percentage of Vehicle-KM by Speed Range: Baseline vs ATIS

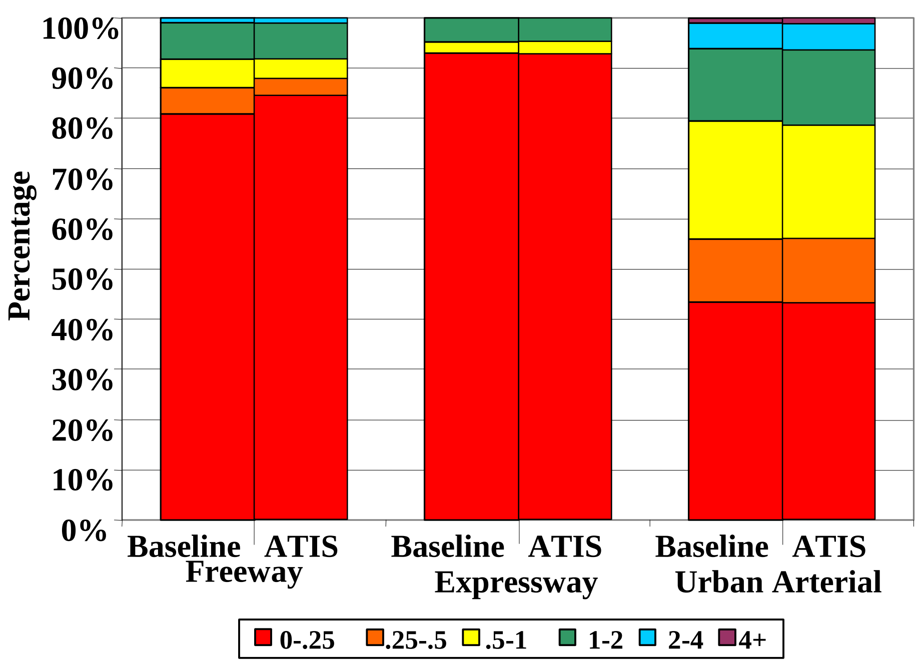

Figure 4.4 Expected Number of Stops Per Vehicle-KM: Baseline vs ATIS

4.2 ATMS Experiment

Overall, system level improvements from the ATMS experiment are larger than either the ATIS or IMS/EMS experiment, as well as more evenly dispersed among origin-destination pairs in the network. The largest impact is seen in system delay reduction, concentrated in scenarios where travel demand and network capacity are close to expectation (v/c ~ 1). That high performance is located close to expectation is not surprising, given that the signal timing plans have been optimized for this conditions. Improved performance is not seen in all scenarios, however, including some cases of reduced throughput and increased delay. These negative impact cases occur in extreme high demand scenarios or in weather conditions, indicating that the signal timing plans optimized for average conditions may be less than optimal under extreme conditions.

Delay Reduction (Figure 4.5). Highest impact on delay reduction occurs in scenarios where demand close to expectation and the weather is clear (e.g., ND6, NE3, NE6). Similarly, reduced delay on the order of 0.5-1.0 minute per traveler may be observed in scenarios where reduced travel demand is paired with reduced roadway capacity from weather effects (EW2, EW6, EW7). Poor performance in terms of delay reduction is observed under high demand scenarios and the snow scenario. On an annual basis, delay is reduced by 0.42 minutes (25 seconds) per traveler. This represents an annualized system delay reduction of 8.3% compared to the Baseline case.

Throughput (Figure 4.6). Impact on throughput is mixed bag of small improvements and reductions. Throughput impact outside of heavy demand and weather cases is negligible. On an annual basis, throughput is reduced by 0.37%, corresponding to roughly 500 additional vehicles unable to complete trips in the peak period over the Baseline case.

Coefficient of Variation. Coefficient of variation has not been calculated for the ATMS experiment to date.

Percentage of Vehicle-Kilometers of Travel By Speed Range (Figure 4.7). The impact on facility speeds is small and indeterminate in nature. Some increase can be observed in high-speed urban arterial travel (40-60 mph), but the largest impact is indicated for freeway facilities. At this point we have not conducted a detailed examination of the data to determine whether this is an impact of travelers choosing more arterial travel because of improved arterial performance or simply randomness.

Expected Number of Stops per Vehicle-Kilometer of Travel (Figure 4.8). Again, tiny positive impacts are indicated for the urban arterial system, while more significant impact is indicated for freeway links in the network. This may be indicative of increased travel load being borne by the arterial system, freeing up capacity on the freeways. This conjecture can be validated by examining facility-level vehicle flow on an annual basis, although we have not calculated such a measure to date. Impacts on the expressways are negligible.

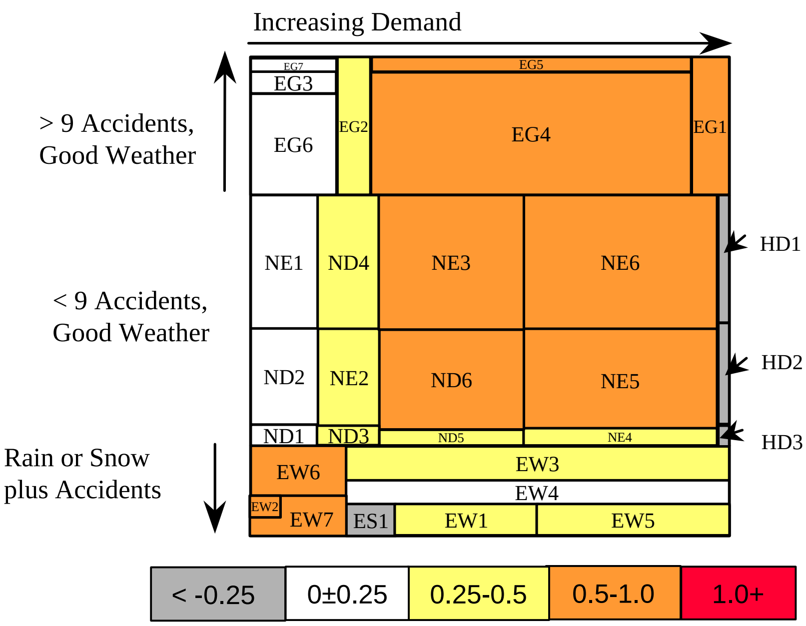

Figure 4.5 Minutes of Delay Reduction: Baseline vs. ATMS

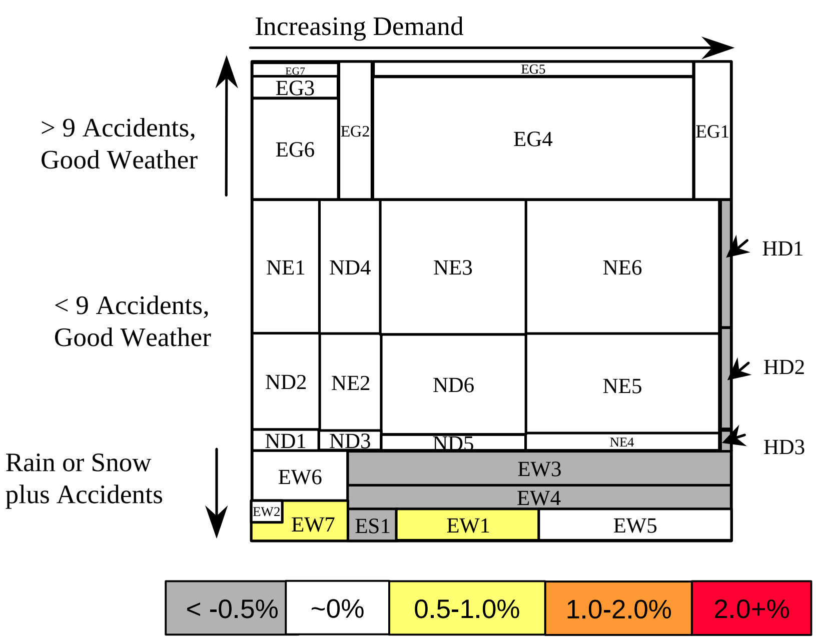

Figure 4.6 Increase in Vehicle Throughput: Baseline vs. ATMS

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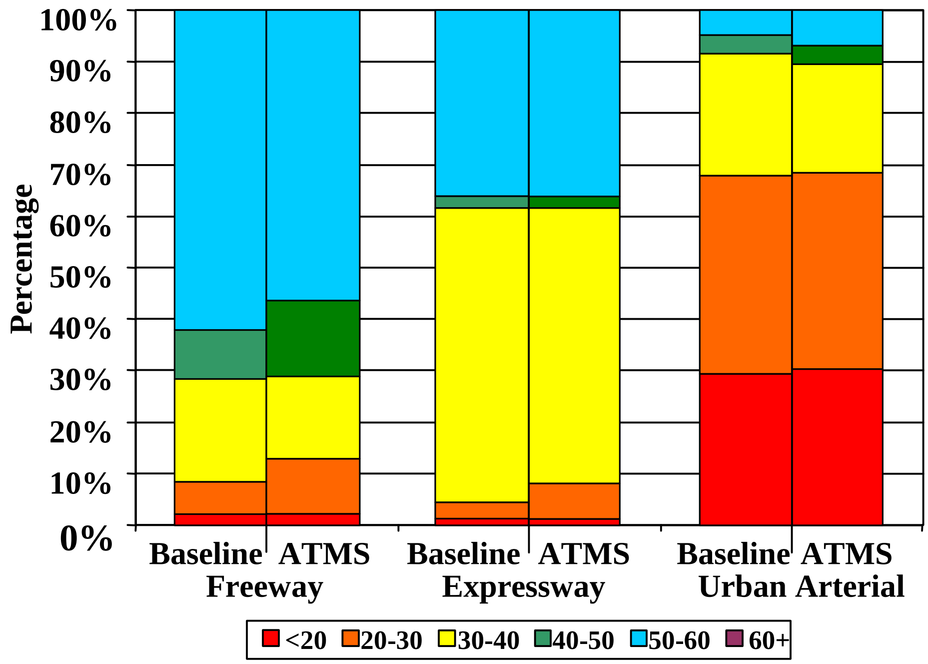

Figure 4.7 Percentage of Vehicle-KM by Speed Range: Baseline vs ATMS

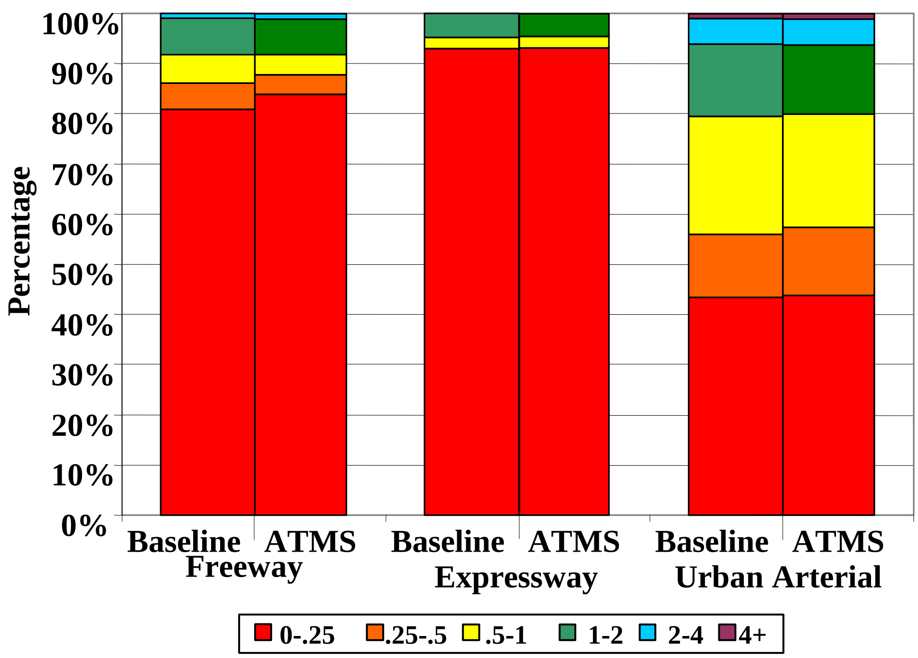

Figure 4.8 Expected Number of Stops Per Vehicle-KM: Baseline vs ATMS

4.3 IMS/EMS Experiment

As one might expect, IMS/EMS impacts are concentrated in scenarios that have major incidents or large numbers of accidents. The timing and location of incidents are critical in terms of IMS/EMS effectiveness. Major disruptions on the freeway when combined with heavy demand or snow show the most significant impact. Benefit is highly concentrated, even in the freeway incident cases, among users traveling particular facilities at particular times. Of note is that although annualized system delay impacts are smallest from IMS/EMS (compared with ATIS and ATMS), the most significant gains in reducing variability were recorded in the IMS/EMS experiment. This result reflects the elimination of a significant number of “extreme outlier” delay cases for origin-destination pairs confronted with major incident-related delay. One may characterize IMS/EMS impacts as the most highly concentrated (of the three sensitivity analyses) in terms of geography, trip timing, and scenario.

Delay Reduction (Figure 4.9). Statistically significant impacts can be observed for five scenarios featuring major incidents (EG1, EG2), heavy demand and accidents (HD1), snow (ES1), or rain and accidents (EW2). Highest impact occurred in the two weather-related scenarios. On an annual basis, delay is reduced by 0.03 minutes (1.8 seconds) per traveler. This represents an annualized system delay reduction of 0.7% compared to the Baseline case.

Throughput (Figure 4.10). Statistically significant impacts on throughput are observed for scenarios combining light demand, poor weather conditions and large numbers of accidents. As with delay reduction, the ES1 (snow) and EW2 (rain plus freeway accidents) scenarios had the highest impact. On an annual basis, throughput is improved by 0.02%, corresponding to 36 additional vehicles completing trips in the peak period over the Baseline case.

Coefficient of Variation. The Baseline case coefficient of variation is 0.2269. Applying this to a trip with an expected duration of one hour, a traveler would have to budget 1.2269 hours (73.6 minutes) to arrive at his/her destination on-time two-thirds of the time. The value obtained in the IMS/EMS experiment is 0.2017, indicating that travel has become slightly more predictable across the system. Under the constraints of our hypothetical one-hour trip, the amount of time needed to budget to be on-time two-thirds of the time is 72.1 minutes.

Percentage of Vehicle-Kilometers of Travel By Speed Range (Figure 4.11). The impact on facility speeds is small. Freeway speeds, counter-intuitively, appear to have been slowed slightly. A roughly 7% increase in 40-50 mph speeds can be observed at the apparent expense of travel in the 50-60 mph range. Although we have not investigated this impact, it is likely that this differences is a result of randomness for a number of links operating just at the 50-mph level.

Expected Number of Stops per Vehicle-Kilometer of Travel (Figure 4.12). Almost no impact, significant or otherwise, can be discerned. What differences that can be seen are below the threshold of randomness in the data.

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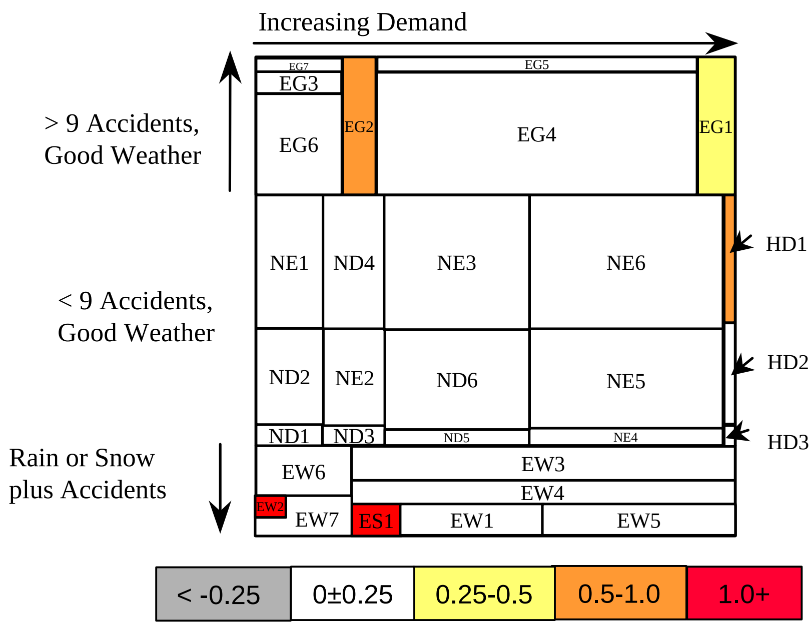

Figure 4.9 Minutes of Delay Reduction: IMS/EMS vs. Baseline

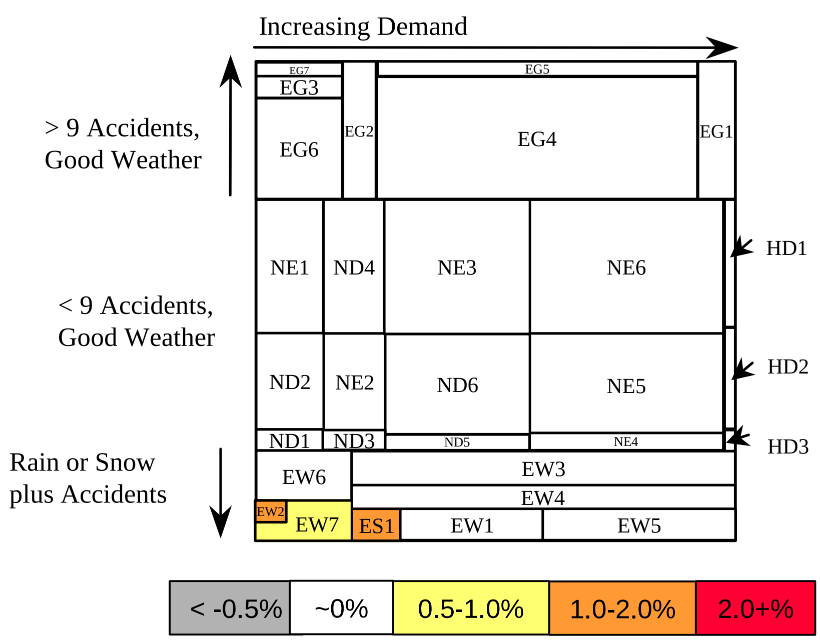

Figure 4.10 Increase in Vehicle Throughput: IMS/EMS vs. Baseline

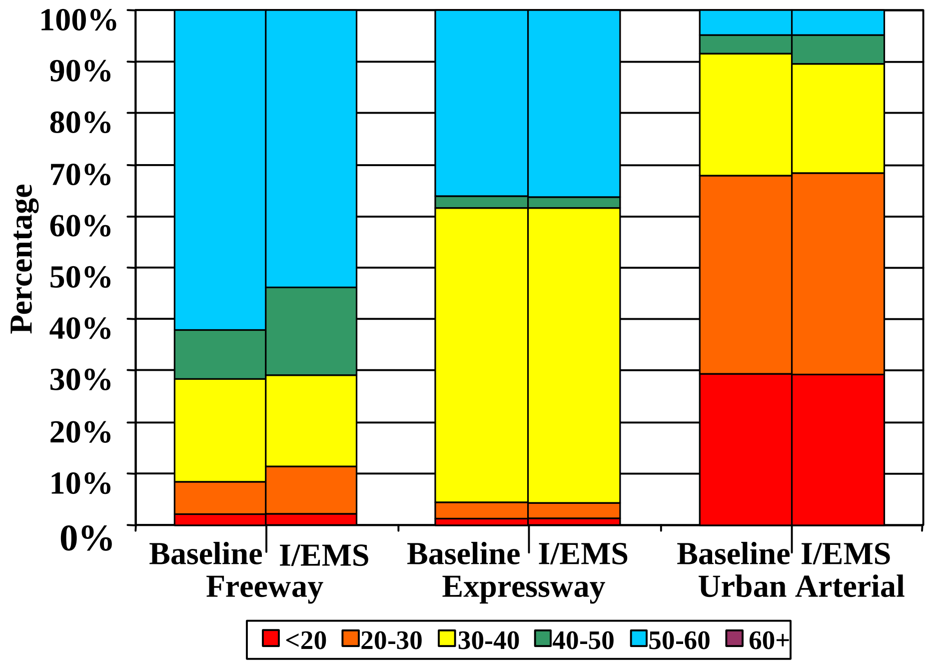

Figure 4.11 Percentage of Vehicle-KM by Speed Range: Baseline vs IMS/EMS

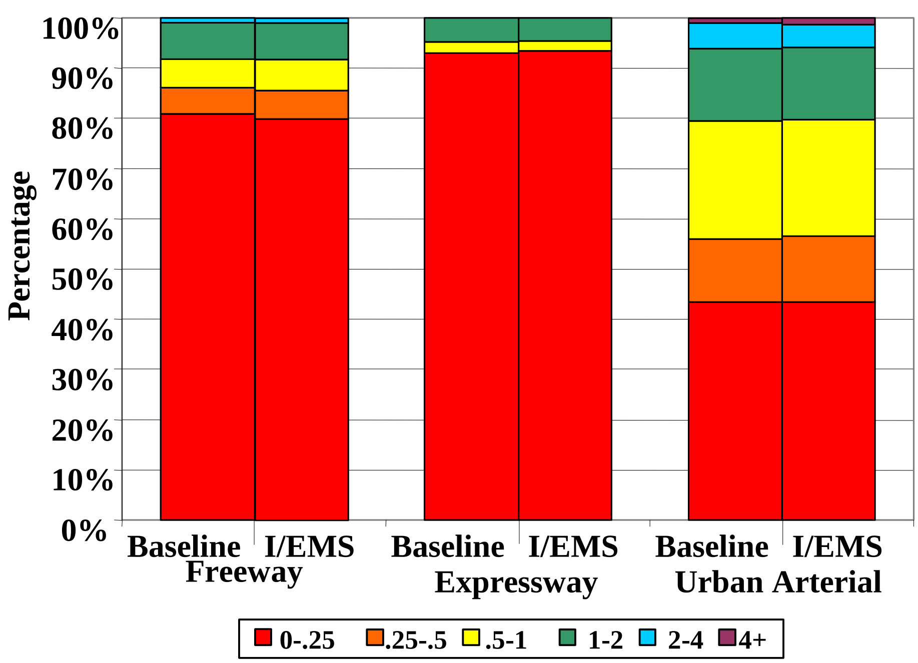

Figure 4.12 Expected Number of Stops Per Vehicle-KM: Baseline vs IMS/EMS

4.4 Enhanced ITS Alternatives Analysis

Unlike the three preceding sensitivity analyses, the Enhanced ITS alternatives analysis reports impacts from both the regional model and the subarea simulation model. This is important for two reasons. First, as trips are diverted to/from the area, modes are shifted, and travel times and distances changed due to corridor improvements, there can be profound and potentially significant impacts outside of the simulation area. These impacts may affect overall travel patterns and the performance of the system in areas far away from the corridor. Including the regional analysis captures these impacts. Second, the regional forecasting process captures the improvements in recurrent and average "expected" conditions within the system. Long term locational and travel decisions concerning trip distribution and mode choice are made based upon these expectations. The simulation model captures operational improvements, response to variation and unusual conditions, and availability of improved information. Shorter term, more flexible responses that cannot be addressed in the regional model are captured in the simulation. Both are needed to provide an overall and complete analysis. Results from the regional model are presented in Section 4.1.1. Results from the subarea simulation model are presented in Section 4.1.2.

4.4.1 Regional Impacts

The regional analysis of the Enhanced ITS alternative was carried out to capture the MDI improvements aimed at average conditions and recurring congestion. In general these include ATMS and other strategies aimed at improving the general operations of a facility, its throughput, and travel time. The ATMS improvements assumed for the Enhanced ITS alternative are primarily along SR-99 and SR-522 and are described in detail in Section 3.5. Network improvements along SR-99 and SR-522 were coded for the alternative and the regional model executed to capture the changes in travel patterns, mode split, and route diversion (assignment). A summary of the regional measures of effectiveness (MOEs) comparing the Enhanced ITS alternative with the MDI Baseline follows. The regional MOEs provided include: daily and AM peak period person and vehicle trips, miles and hours traveled by mode; subarea trip summaries; and average distance and travel times. Overall, the impacts of the improvements at the regional level are logical, but relatively small. A slight shift from transit to the auto modes is seen due to the improvements. Trips are longer and have improved speeds. There is also a diversion of trips to the simulation area from alternate paths.

Tables 4.1 through 4.3 summarize the daily person and vehicle travel for the region. The same overall person trips were used as inputs for both alternatives and as expected they remain the same. There is a slight drop in transit person trips and non-carpool vehicle trips. The daily vehicle miles traveled increases while the hours remain the same reflecting faster travel and longer trips. Carpools make slightly shorter trips which is reasonable since the improvements were made to general use facilities (SR-99 & SR-522).

Regional Travel: Daily Person and Vehicle Trips				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
Daily Trips				
Person Trips	11,573,681	11,573,680	-1	0.00%
Non-Carpool Vehicle Trips	8,679,492	8,679,234	-258	0.00%
Carpool Vehicle Trips	12,643	12,647	4	0.03%
Transit Person Trips	253,861	253,517	-343	-0.14%

Table 4.1: Daily Person and Vehicle Trip Comparison

Regional Travel: Daily Vehicle Miles and Hours Traveled				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
Daily Vehicle Miles Traveled				
Non-Carpool	70,548,712	70,653,272	104,560	0.1%
Carpool	226,241	225,511	-730	-0.32%
Transit	143,043	143,043	0	0.00%
Daily Vehicle Hours Traveled				
Non-Carpool	2,222,879	2,223,774	895	0.0%
Carpool	6,801	6,780	-21	-0.31%
Transit	8,268	8,258	-10	-0.12%

Table 4.2: Daily Vehicle Miles and Hours Traveled

Regional Travel: Daily Person Miles and Hours Traveled				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
Daily Person Miles Traveled				
Non-Carpool	100,106,160	100,230,656	124,496	0.1%
Carpool	748,612	745,846	-2,766	-0.37%
Transit	1,885,618	1,879,954	-5,664	-0.30%
Daily Person Hours Traveled				
Non-Carpool	3,084,866	3,078,922	-5,944	-0.2%
Carpool	22,131	21,818	-313	-1.42%
Transit	229,442	228,713	-729	-0.32%

Table 4.3 Daily person Miles and Hours Traveled

Tables 4.4 through 4.6 provide similar measures for the AM peak period. Similar trends of a slight reduction in transit use and longer, faster trips are also observable. However, diversion offsets the speed improvements in the AM peak as shown by the slightly higher percentage increase in person hours traveled in LOV vehicles versus person miles traveled.

Regional Travel: AM Peak Period Person and Vehicle Trips				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
AM Peak Period Trips				
Person Trips	2,232,811	2,232,796	-16	0.00%
Non-Carpool Vehicle Trips	1,529,112	1,529,126	14	0.00%
Carpool Vehicle Trips	9,483	9,485	3	0.03%
Transit Person Trips	72,504	72,371	-133	-0.18%

Table 4.4: AM Peak Period Person and Vehicle Trips

Regional Travel: AM Peak Period Vehicle Miles and Hours Traveled				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
AM Peak Vehicle Miles Traveled				
Non-Carpool	13,898,693	13,918,142	19,449	0.1%
Carpool	168,983	168,387	-596	-0.35%
Transit	36,581	36,581	0	0.00%
AM Peak Vehicle Hours Traveled				
Non-Carpool	485,734	486,385	650	0.1%
Carpool	5,944	5,923	-21	-0.35%
Transit	2,116	2,115	-2	-0.08%

Table 4.5: AM Peak Period Vehicle Miles and Hours Traveled

Regional Travel: AM Peak Period Person Miles and Hours Traveled				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
AM Peak Person Miles Traveled				
Non-Carpool	20,913,894	20,929,332	15,438	0.1%
Carpool	559,213	557,020	-2,194	-0.39%
Transit	621,272	617,896	-3,376	-0.54%
AM Peak Person Hours Traveled				
Non-Carpool	717,860	719,097	1,237	0.2%
Carpool	19,565	19,581	16	0.08%
Transit	66,920	66,703	-217	-0.32%

Table 4.6: AM Peak Period Person Miles and Hours Traveled

Tables 4.7 and 4.8 illustrate the impact of the Enhanced ITS alternative improvements on throughput and trips attracted (diverted) to the simulation area. Table 4.7 provides the AM peak period trips to, from, and through the subarea that are provided to the simulation model for analysis. Here the change from 1990 to the MDI baseline shown earlier is reversed. More trips and a higher percentage are included in the simulation as people take advantage of the reduced congestion the improvements provided and divert back to, from, or through the subarea. This diversion is also reflected in the AM peak period screen line volumes shown in Table 4.8 (Figure 4.13 provides the screen line locations). The screen line volumes show more noticeable percent changes than the overall regional travel measures as they capture more localized effects, and both mode split and diversion impacts. Screen line 43, Locust Way, shows the highest increase in travel reflecting the attraction to SR-522 caused by the ATMS coordinated signal improvements.

It is interesting to note that there is even a 1% increase in volumes across Lake Washington on Screen line 32 as travelers reorient how they enter the subarea. Note, that if area-wide rather than corridor improvements were made the diversion impacts shown by the screen line analysis would not be as noticeable.

Table 4. 9 reveals how the trips, miles traveled, and times are interrelated and interact due to the Enhanced ITS alternative improvements. It includes both the impacts of the regional recurrent delay analysis, and the rolled up travel time impacts of the simulation representative day analysis used to capture unusual events and improved information. The table provides a breakout by origin and destination of the AM Peak Period LOV (non-carpool) vehicle trips that travel to, from, or through the simulation area. Four areas are defined: 1. The simulation area; 2. The area south of the simulation area within the North corridor influence area (including the Seattle CBD); 3. The area north of the simulation area within the North corridor influence area; and 4. The area outside of the North Corridor. These regions are mapped in Figure 4.14.

The table shows an increase in trips and average distance and a decrease in average travel time when the overall trips are looked at without disagregation. Again, this illustrates longer faster trips overall. It is more revealing, however, to look at some of the individual cell values. For example, trips from the south (area 2) and trips to the north (area 3) have higher average travel times. These trips must travel in the reverse peak direction in order to be included in this summary which is against the improved (but fixed) signal coordination. As the peak direction travel improves the reverse direction is impacted. The highest percent improvement in travel times is for the trips from the north to and through the study area (4.03%). These trips also show an increased average distance. This is logical since these trips can take advantage of both the SR-99 and SR-522 improvements. Trips from and to outside of the corridor (area 4) increase while their average distance decrease. Again, this is the result of new relatively shorter trips being attracted to the simulation area.

Regional And Sub-Area Trips: AM Peak Period				
	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
Regional SOV	1,529,112	1,529,126	14	0.00%
SubArea SOV	256,520	257,591	1,071	0.42%
% SubArea SOV	16.78%	16.85%		
Regional HOV	9,483	9,485	2	0.02%
SubArea HOV	2,230	2,242	12	0.54%
% SubArea HOV	23.52%	23.64%		

Table 4.7: AM Peak Period Subarea Vehicle Trips.

As shown, the MDI alternative impacts are small at the regional level. These impacts, however, are consistent and will increase as travel demand continues to grow at a faster pace than infrastructure enhancements, and as the level of ITS improvements increase. Table 4.9 captures travel time impacts at both the regional and subarea level. Table 4.9 also highlights the distribution of impacts and how they change for travel from or to the subarea.

AM Peak Period Screen Line Volumes (Vehicles)			
Screen Line	Base	Alternative	% Change
Ship Channel (35)	97,982	98,227	0.25%
Lake Washington (32)	45,243	45,723	1.06%
County Line (42)	56,598	56,988	0.69%
Locust Way (43)	44,898	45,572	1.50%
128th Street SW (46)	55,841	56,470	1.13%

Table 4.8: AM Peak Period Screen Lines Volumes

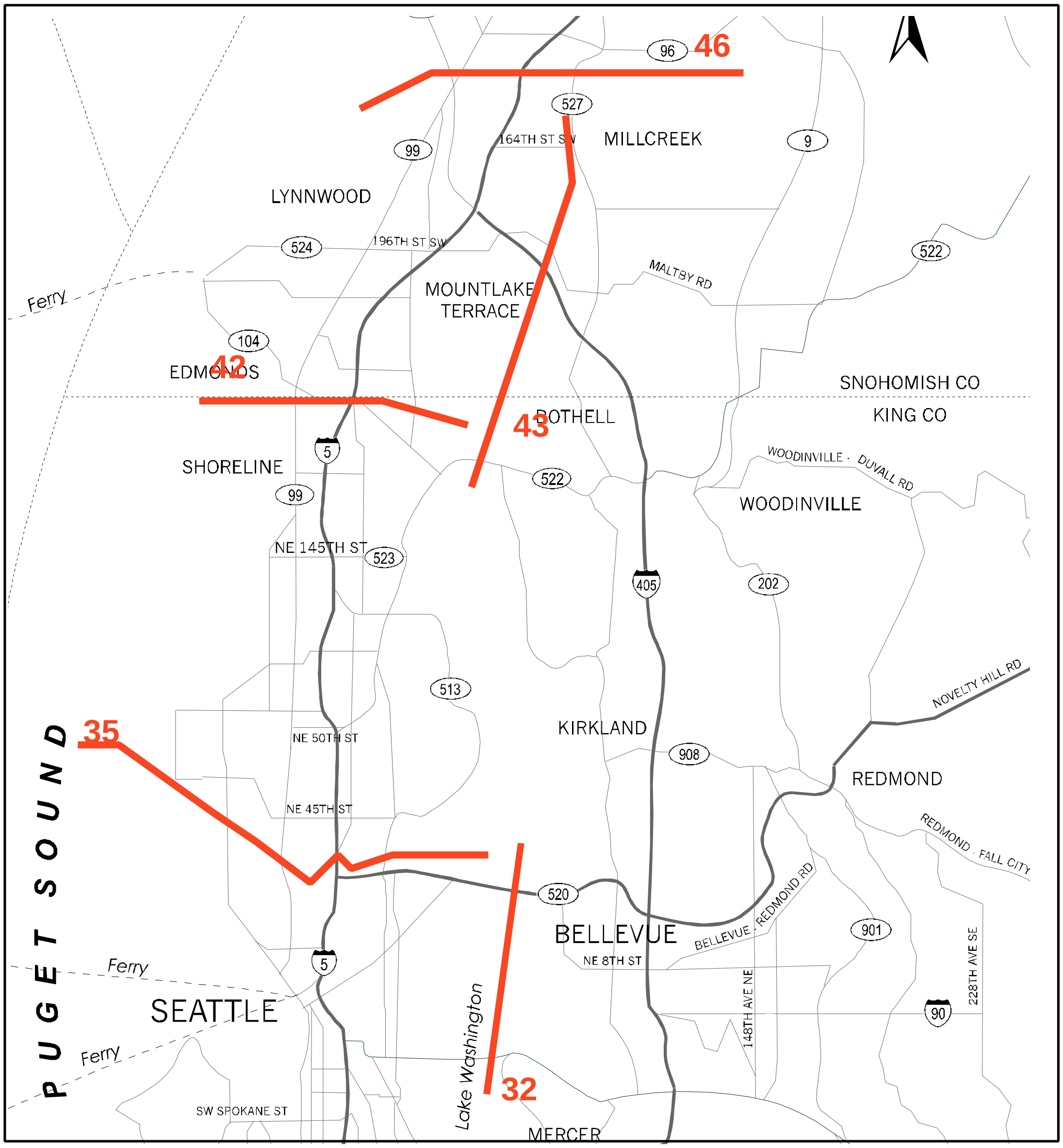

Figure 4.13: Screen Line Locations

AM Peak Period LOV Travel To, From, Through Simulation Area									
	Base			Alternative			% Change		
	Vehicle Trips	Average Distance	Average Time	Vehicle Trips	Average Distance	Average Time	Vehicle Trips	Average Distance	Average Time
From:									
1 = Simulation area	173485	6.06	13.64	173667	6.08	13.62	0.10%	0.38%	-0.18%
2 = Corridor South	14192	6.92	14.89	14270	6.93	15.35	0.56%	0.24%	3.07%
3 = Corridor North	24921	11.81	25.74	25241	11.87	24.70	1.28%	0.50%	-4.03%
4 = Outside Corridor	43922	41.73	76.60	44413	41.59	75.73	1.12%	-0.33%	-1.15%
To:									
1 = Simulation area	174862	8.27	18.25	175058	8.28	18.09	0.11%	0.01%	-0.92%
2 = Corridor South	42269	11.74	24.39	42363	11.73	23.80	0.22%	-0.09%	-2.42%
3 = Corridor North	9542	19.14	38.35	9796	19.22	38.50	2.67%	0.44%	0.38%
4 = Outside Corridor	29847	38.56	66.85	30375	38.46	66.48	1.77%	-0.26%	-0.56%
Overall	256520	12.77	25.67	257591	12.82	25.51	0.42%	0.36%	-0.62%

Distances in Miles, Times in Minutes

Table 4.9 AM Peak Period Travel To, From, Through Travel Comparson (LOV Vehicle Trips)

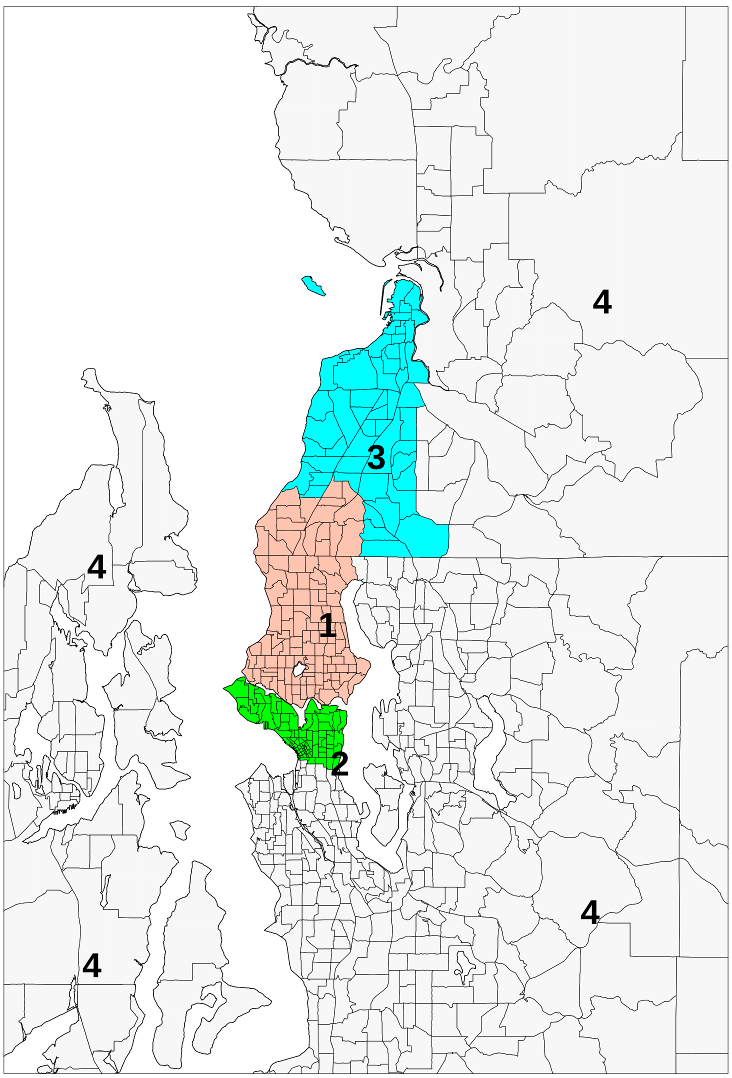

Figure 4.14: Travel Time Comparison Areas

4.4.2 Subarea Impacts

Overall, the Enhanced ITS alternative improves system performance through delay reduction and increases in throughput. Some moderate reduction in subarea stops is also indicated. The performance of ATIS users is significantly enhanced in comparison with the ATIS sensitivity analysis, likely because of the provision of arterial data in the Enhanced ITS alternative. Based on our preliminary analysis, there is significant potential benefit in the use of arterial detectors to support both improved signal timing as well as more comprehensive, effective ATIS. Not all functional relationships are synergistic, however. ATIS and IMS/EMS tend to be effective in the same types of conditions, and although they do not appear to impede on one another, there does appear to be some dilution of impact. Another observation is that under extreme demand or snow scenarios, system level improvements from ATIS and IMS/EMS roughly balance out inefficiencies associated with the new signal timing plan from the ATMS experiment.

<u>Delay Reduction</u> (Figure 4.15). Delay reduction can be characterized as more robust over the range of scenarios than in any of three sensitivity analyses. Improvements associated with the improved signal timing plan can be observed in the scenarios with close-to-expected demand and good weather. Under conditions of high demand or many accidents, impacts associated with ATIS and IMS/EMS can be observed. On an annual basis, delay is reduced by 0.50 minutes (30 seconds) per traveler. This represents an annualized system delay reduction of 9.8% compared to the Baseline case, even when overall system demand has increased by roughly 0.4% from the Baseline.

<u>Throughput</u> (Figure 4.16). Improvements to throughput are seen under a wide range of weather or high-demand conditions. In the snow scenario (ES1) some reduced throughput can be observed. On an annual basis, throughput is improved by 0.31%, corresponding to roughly 450 additional vehicles completing trips in the peak period over the Baseline case. This 0.31% improvement is also indicative of the increased travel demand in the Enhanced ITS alternative.

<u>Coefficient of Variation</u>. The value obtained under the Enhanced ITS alternative is 0.2223, indicating that travel has become slightly more predictable across the system than the Baseline case (0.2269). This improvement is larger than seen for ATIS (0.2248) but smaller than for IMS/EMS (0.2017). This apparent "retreat" from the IMS/EMS level is likely reflective of increased demand borne in the Enhanced ITS alternative.

<u>Percentage of Vehicle-Kilometers of Travel By Speed Range</u> (Figure 4.17). For both freeway and arterial facilities, higher- and lower-speed travel make small gains at the expense of more moderate-speed travel. For example, high-speed freeway travel (60+ mph) increases by 4% while low-speed freeway travel (10-20 mph) also increases by roughly 3%. This trend is also reflected in arterial travel.

<u>Expected Number of Stops per Vehicle-Kilometer of Travel</u> (Figure 4.18). A moderate improvement in stops can be observed for freeway travel. The amount of travel occurring in the system with fewer than 0.25 stops per kilometer increases by roughly 7%. Impacts on non-freeway facilities are negligible.

ATIS User Impacts. At this stage, only first-level tabulation of user impacts have been completed. ATIS users in the Enhanced ITS case improve their performance with respect to both the Baseline case and the ATIS sensitivity analysis. This is due in large part to the real-time travel time archive of arterial data from SR99 and SR522 being made available to ATIS users. ATIS users have a subarea travel time of 18.6 minutes compared to a baseline average travel time of 19.1 minutes and a travel time of 18.9 minutes in the ATIS experiment. This improvement must also be viewed in light of marginally increased overall travel demand, which when applied independently, causes a general increase in travel times across all traveler classes.

DRAFT

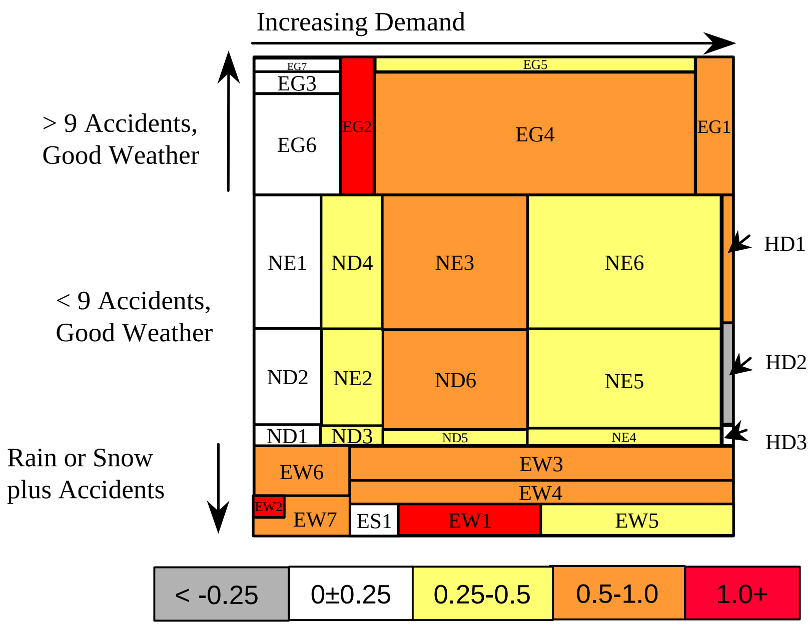

Figure 4.15 Minutes of Delay Reduction: Baseline vs. Enhanced ITS

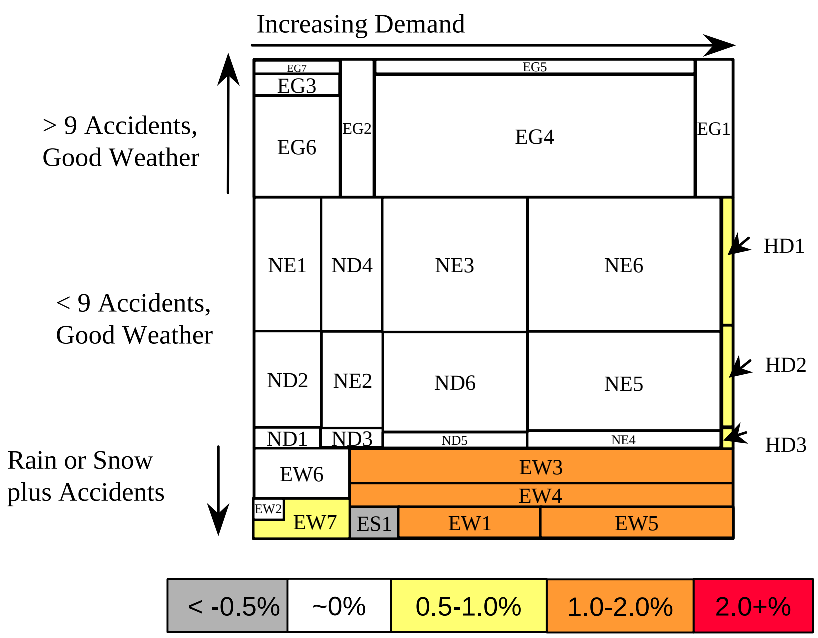

Figure 4.16 Increase in Vehicle Throughput: Baseline vs. Enhanced ITS

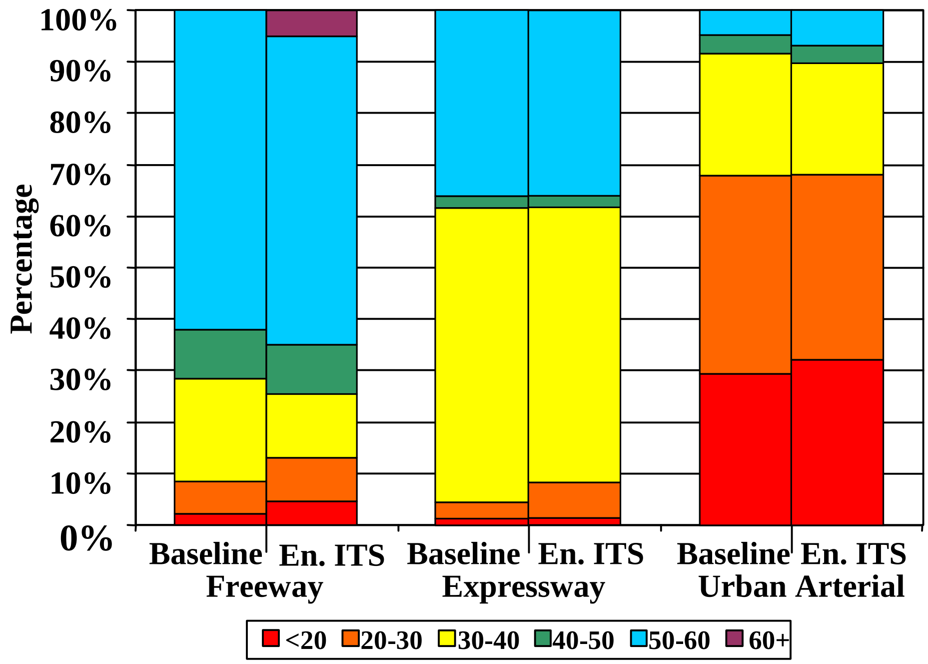

Figure 4.17 Percentage of Vehicle-KM by Speed Range: Baseline vs En. ITS

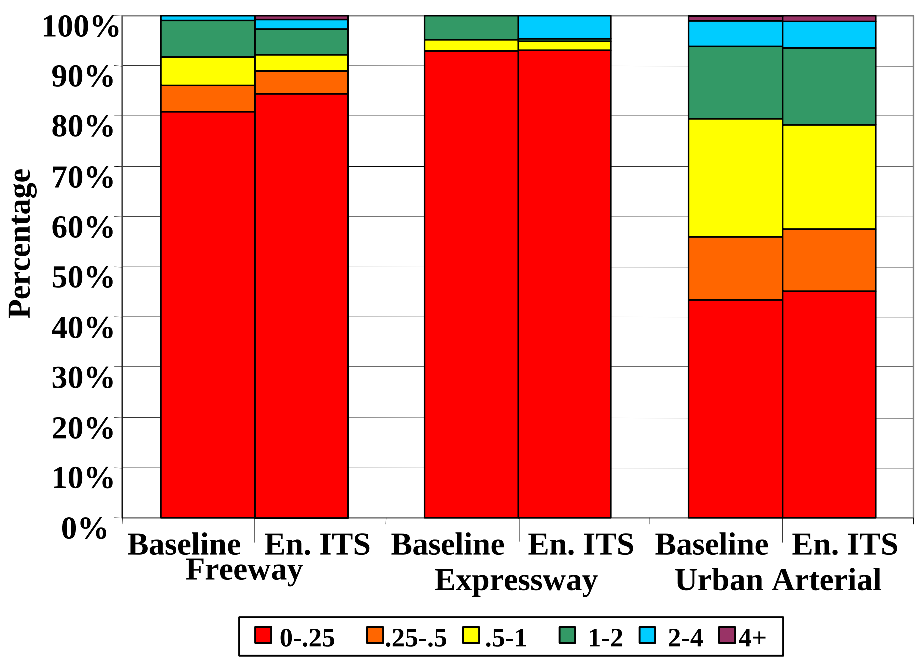

Figure 4.18 Expected Number of Stops Per Vehicle-KM: Baseline vs En. ITS

SECTION 5: CONCLUSIONS

This section presents summary of significant results obtained to date and a discussion of their implications. Results from additional experimentation will be included in the 1 April 1999 final report. In Section 5.2, implications of these results are examined with respect to directing the limited Mitretek time and resources available between now and the final report deadline.

5.1 Implications of Results

A key feature of the MMDI evaluation effort is in the identification of benefits associated with the deployment of integrated ITS, rather than stove-pipe functional or jurisdictional systems. The Seattle MMDI deployment has examples of both functional (utilization of arterial congestion data for both traffic signal control and ATIS) and jurisdictional cooperation (traffic signal coordination along major arterial corridors).

The *benefit of jurisdictional cooperation for signal control* is illustrated in the impacts associated with the ATMS experiment. The combination of better data on arterial queue length in the AM peak and the coordination of signals at variable progression speeds (both major and minor) is projected to reduce system-wide delay by 8.3%. The subarea model available for this effort and the experiments performed are not detailed enough to produce a traffic signal timing plan that can be directly implemented in the field. However, for traffic engineers in Seattle, Lynnwood and other jurisdictions in the North Corridor, the 8.3% delay reduction provides a quantitative estimate of potential benefit that can be used in prioritizing the development of a detailed plan for SR99 or SR522. Further, the delay reduction figure demonstrates to participating jurisdictions that cooperation on timing plans has a quantifiable potential benefit, bolstering an argument that was heretofore purely conjecture.

Another useful observation concerning jurisdictional cooperation for signal control is that although well-timed plans are generally beneficial, the range of conditions (particularly the combination of weather and travel demand variations) seen in the North Corridor cannot always be satisfied with a single fixed plan. A case can be made, therefore, that even more benefit could reasonably be expected if alternative plans could be implemented for particular peak periods based on observed conditions. For example, an arterial corridor plan featuring shorter cycle length and faster progression speeds could be developed for light demand conditions. This signal control strategy would require cooperation between jurisdictions on a day-to-day basis to select the appropriate coordinated plan from a list of approved alternatives.

The impact of *integrating arterial congestion data for signal control with ATIS* is illustrated by examining impacts between the ATIS experiment and the Enhanced ITS alternative. Pre-trip users of detailed freeway congestion information in the ATIS experiment have roughly 0.5 minute lower delay on average than users of traffic advisories (radio or VMS) in the Baseline case. Pre-trip users of traffic congestion information in the Enhanced ITS alternative experience 0.8 minutes lower delay on average than users of traffic advisories in the Baseline case. While some of this effect is obscured by the concurrent addition of IMS/EMS and ATMS improvements, the result indicates that there may be significant value in providing arterial as well as freeway travel time estimates to commuters at the corridor level.

ATIS impacts should be interpreted understanding the focus of the evaluation network on corridor-specific travel. Travelers planning for long trips from the extreme north to south within the Puget Sound region, say Everett to Tacoma, have freeway-to-freeway alternatives (I-5 vs. I-405) that are not represented by the current North Corridor model. The range of choices is limited to the corridor level (SR99 vs. I-5), so we expect some underestimation of benefit for these particular kinds of trips. Providing arterial congestion data is likely more useful for the inter-corridor, moderate length tripmaker (say Edmonds to the University of Washington campus) than for the long regional tripmaker.

Another goal for MMDI evaluation is to *quantify the overall system impacts of integrated ITS compared with isolated deployments of ITS functional components*. A comprehensive assessment is not possible here given that the Seattle MMDI does not represent the deployment of an end-state fully integrated ITS, nor do we project such a deployment in this analysis. One can, however, examine the results of the experiments for indications, supportive or otherwise, with regard to overall impact of integrating ITS. Here, we do this by comparing the impacts of isolated functional components (ATIS, ATMS, IMS/EMS) with the Enhanced ITS alternative. The Enhanced ITS alternative can be depicted as the concurrent deployment of each isolated functional element, with limited integration between ATMS and ATIS (based on the integration of arterial congestion information for traffic signal control with ATIS).

Sensitivity Analysis	**Delay Reduction vs. Baseline**	**Increase in Throughput vs. Baseline**
ATIS	1.51%	0.02%
ATMS	8.26%	-0.37%
IMS/EMS	0.70%	0.02%
Isolated Hypothetical Sum	10.47%	-0.33%

Alternatives Analysis	**Delay Reduction vs. Baseline**	**Increase in Throughput vs. Baseline**
Enhanced ITS	9.8%	0.31%

Table 5.1 Delay Reduction and Throughput Impacts, Sensitivity and Alternatives Analysis

Table 5.1 depicts delay reduction and throughput statistics (versus Baseline) associated with the three sensitivity analyses and the Enhanced ITS alternatives analysis. Each reported impact is the annualized impacts calculated by computing the weighted sum of impact in each scenario. In addition, an "Isolated Hypothetical Sum" is presented, calculated simply by adding up the impacts of each isolated component.

In a direct comparison of impacts from the Isolated Hypothetical Sum with impacts from the Enhanced ITS alternative, one can see that delay reduction is less than additive, while throughput improvement is greater than additive. This direct comparison is somewhat misleading, however, considering the fact that the Enhanced ITS alternative is conducted under higher travel demand than any of the sensitivity analyses (see Section 3.4 for discussion). The additional travel demand has the impact of depressing delay reduction while increasing throughput measures. Additional experimentation may clarify the situation, for example by re-running the Enhanced ITS alternative under the lower Baseline demand.

An examination of the conditions where benefit can be expected from each functional component is illustrative of how these functional components may be interacting. For example, IMS/EMS and ATIS have highest impact in many of the same situations, primarily corresponding to freeway incident cases and extreme weather cases. ATMS impacts are insensitive to incidents and have highest impact where the ratio of travel demand to roadway capacity is close to expectation. In scenarios where impact by functional component overlaps, impacts from adding in a new functional component is diluted by the simple fact that there is less delay to eliminate. The converse of this situation can be seen in the heavy demand and snow cases where the signal control plan associated with the ATMS experiment actually adds delay to the system (detailed in Section 4.2). In these cases, IMS/EMS and ATIS appear more effective because there is more delay to avoid than in the Baseline case.

Another observation that can be made is that the impacts associated with the Enhanced ITS alternative are relatively small when compared with the impacts projected for fully integrated end-state ITS deployments like the one tested in the Seattle 2020 analysis [2]. The difference in impact is reflective of the significant difference in how much ITS is deployed in each case. For example, the 2020 ITS Rich alternative features comprehensive adaptive ATMS arterial control, integrated freeway/arterial surveillance supplemented by probe vehicles for ATIS, and high usage rates for advanced pre-trip and en-route traveler information services. The Enhanced ITS alternative is best viewed as an evolutionary step towards such a fully integrated ITS deployment.

5.2 Proposed Work Plan to April 1999

A limited number of extensions to the experimental plan reported in this document may be considered for analysis and conclusion in the planned 1 April 1999 final report document. A list of these extensions is presented here in a priority order established by Mitretek. This priority order, however, is based on feedback from the 10 December 1998 preliminary results briefing in Washington, DC to JPO, Volpe, and SAIC MMDI evaluation team members and the 11 December teleconference on the same topic with the Seattle MMDI evaluation liaison.

- Isolate benefit of arterial congestion data supplied for ATIS. Thirty simulations are planned repeating the ATIS experiment with arterial data available as well as freeway congestion information. The baseline signal timing plan will be used for this experiment.

- Complete sensitivity analysis for ATIS, IMS/EMS, including explicit modeling of pre-trip versus en route ATIS. In support of national-level benefit/cost calculation efforts, Mitretek will conduct runs for a subset of the North Corridor scenarios to examine the impact of ATIS usage rates of (1%, 2%, 6% and 10%). A similar analysis will be performed for IMS/EMS impacts considering a 12.5% reduction in incident duration. Preliminary results reported in this document reflect the default 6% usage rates for ATIS and a 25% reduction in incident duration.

- Re-run ATIS, Enhanced ITS with time-shifting and trip postponement. To date in our analysis, only route choice has been considered for traveler decision-making with ATIS. Mitretek began work in implementing model routines within PRUEVIIN to address this issue in October 1998 based on feedback our Seattle site visit in September 1998. The technique for MMDI evaluation is based on a earlier method developed at Mitretek [20]. Implementation of that module was not completed in time for this preliminary report. In support of national-level benefit/cost calculation efforts, Mitretek may also conduct a separate sensitivity analysis examining the impacts of time shifting and trip postponement independent of route choice for a subset of the 30 scenarios.

- Conduct "second-pass" simulation analysis of Enhanced ITS using changes to regional model from PREUVIIN feedback. This analysis is outlined in the April 1998 evaluation plan.

- Examine impacts of ATIS using non-uniform market penetration. The observation from these experiments that ATIS benefits are non-uniform based on trip patterns and trip timing brings into question the accuracy of our current uniform market penetration assumption. Previous work by Mitretek on a toy network [21] indicates that ATIS benefits may be underestimated if a uniform market penetration assumption is made, both for user benefits and for system impacts. This analysis technique can be adapted for use with PRUEVIIN and the North Corridor network. IPAS contractors conducting ATIS surveys in Seattle, in conjunction with Mitretek, have designed survey questions to test for empirical evidence that users tend to be geographically clustered. Based on responses to this survey, Mitretek will adapt the current analysis technique, implement and repeat the ATIS experimental plan.

Based on this prioritization, Mitretek will not have time or resources to conduct the following extensions, although they may be considered for analysis after 1 April 1999.

- Conduct MMDI transit-based project evaluation.

- Examine impact of changes in overall traveler information usage (radio + TV + web).

- Consider a 2005 alternative case. Although such an alternative may be useful to the national benefit/cost calculation, the design and coding of a 2005 Baseline case and a 2005 Enhanced ITS case is likely to be too large an undertaking between now and April 1999.

- Examine impact of higher levels of jurisdictional cooperation for real-time traffic signal control.

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